Integrated Aquatic Vegetation Management Plan for Blue Lake, Fairview, Oregon

Prepared for:
Oregon Department of Environmental Quality, Metro Regional Authority, and Interlachen Homeowners Association

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Executive Summary

Blue Lake, located in Fairview, is on the1998 Oregon Department of Environmental Quality (ODEQ) 303(d) list of water quality impaired water bodies for violating the upper pH standard (8.5) and supporting abundant aquatic weeds and algae. The lake is eutrophic and has high algal productivity, especially in mid to late summer. Curlyleaf pondweed (*Potamogeton crispus*), a non-native, invasive, aquatic plant species, restricts access to and use of Blue Lake by humans. Human uses of the lake which have been impaired include boating, water skiing, fishing, and swimming.

Development of the current Integrated Aquatic Vegetation Management Plan was driven by the need for an integrated, adaptive management strategy which would address not only the control and prevention of invasive, nuisance plants but also their interaction with algal productivity and water quality, especially pH. The overarching goal of the Blue Lake Integrated Aquatic Vegetation Management Plan is to control nuisance aquatic vegetation so that:

- human recreational and aesthetic use of the lake is facilitated,
- acceptable water quality conditions are maintained,
- and natural functioning of lake aquatic systems is not impaired.

These goals can best be met by preventing new weed introductions and a combination of small-scale physical and mechanical methods and larger-scale chemical treatment. Prevention efforts should aim to educate and inform permanent residents and visitors about how nuisance plants are transported and how to prevent accidental and deliberate introductions of nuisance species. Because the necessary permits for using aquatic herbicides cannot be obtained before the next growing season, a short-term strategy is recommended that can meet some of the management goals.

The short-term strategy focuses on implementing aquatic vegetation management techniques that are effective around docks and waterfronts in combination with mechanical harvesting to maintain boating access to open water areas. The long-term strategy includes use of selective herbicides to manage nuisance aquatic vegetation along with the small-scale treatment around docks, if necessary.

SHORT TERM STRATEGY	LONG TERM STRATEGY
Prevention	* Prevention
Bottom barriers	* Bottom barriers
Hand pulling/raking	* Hand pulling/raking
Sediment agitation	* Sediment agitation
Mechanical harvesting	* Chemical control
Monitoring	* Monitoring
Permit development	Permit maintenance

Monitoring is an important element of an integrated aquatic vegetation management plan. Regular monitoring of plant populations and water quality will enable modification of the management plan to accommodate changes in the lake that occur following implementation of management actions. Monitoring should include twice yearly aquatic plant surveys; monthly measurement of water quality parameters and water chemistry assays; and phytoplankton sampling from June through September. A toxic algae response plan should also be developed that provides a clear protocol for action when potentially toxic algae are present in this high-use lake.

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Introduction

Native aquatic vegetation provides several benefits in Oregon lakes. Aquatic plants stabilize near shore sediments, provide food and habitat for fish and wildlife, and contribute to the cycling of nutrients that maintains aquatic ecosystem function. The introduction of non-native, noxious weeds to a lake can degrade fish and wildlife habitat and water quality. In addition, the dense surface mats that are formed by noxious aquatic plants interfere with recreational use of lakes.

Native plants have natural predators or diseases that keep their populations down. Invasive plants do not have the same biological control mechanisms outside their native environment, which allows unchecked growth. Many nuisance and invasive aquatic plants, like Eurasian watermilfoil (*Myriophyllum spicatum*) and Brazilian elodea (*Egeria densa*), achieve displacement of native species by rapid spring growth. The resultant canopy that is formed over the native plants reduces the available light and puts them at a competitive disadvantage.

Blue Lake, located in Fairview, is just one of many Oregon lakes which have been impacted by aquatic nuisance plants. Human uses of the lake which have been impaired include boating, water skiing, fishing, and swimming. Blue Lake and the surrounding lands have undergone increasing urbanization in the last half century. Much of what was once agricultural land has been developed into residential areas, and the hydrology of the area has been altered by, among other factors, the development of underlying aquifers into a well field. Increasing urbanization has led to increased human use of the lake which is a likely vector for the invasion of Blue Lake by non-native, aquatic nuisance species of plants.

The non-native, aquatic plant which was the most problematic from the 1970's through the 1990's in Blue Lake was Eurasian watermilfoil (*Myriophyllum spicatum*). Plant dominance patterns have changed dramatically since then, with curlyleaf pondweed (*Potamogeton crispus*), another non-native, invasive aquatic plant species, now restricting access to and use of the lake by humans.

Past management activities have not been integrated into an overall management plan for the lake but were focused on a single species, Eurasian watermilfoil (see Beak, 1979 and 1983). Development of the current Integrated Aquatic Vegetation Management Plan was driven by the need for an integrated, adaptive management strategy which would address not only the control and prevention of invasive, nuisance plants but also their interaction with algal productivity and water quality, especially pH. This plan will need to be updated periodically to reflect changing lake conditions and newer management techniques.

Problem Statement and Management Goals

Problem Statement

Blue Lake is on the1998 Oregon Department of Environmental Quality (ODEQ) 303(d) list of water quality impaired water bodies for violating the upper pH standard (8.5) and supporting abundant aquatic weeds and algae. There are three major stakeholder groups with lake management concerns: the permanent residents who own property on or near the lake; Metro, which owns, maintains, and operates the public park on the north shore of the lake; and ODEQ which must develop Total Maximum Daily Loads for the lake in 2004. Other stakeholders include the Oregon Department of Fish and Wildlife, which stocks rainbow trout in the lake; the City of Portland, which periodically pumps water into Blue Lake to raise water levels; Multnomah County and the City of Fairview.

The lake is heavily used by the permanent residents, especially in the summer, for boating, swimming, water skiing, and fishing. The lake is also popular with the general public who visit Blue Lake Regional Park. Park visitors swim in the lake at a designated swimming beach and can rent small boats from the park at a boat dock. The park also has a boat ramp which is open to public use during the off season (October to April). The lake is valued for its aesthetics and for more passive uses such as wildlife viewing, especially bird watching, and outdoor gatherings.

Abundant growth of aquatic plants in Blue Lake, especially in the shallow east and west ends of the lake, has impaired use of the lake by humans. Swimmers and water skiers get entangled in it, boat motors and fishing lines get fouled, and decaying mats of aquatic plants are unsightly and smelly. Property values are, to a great extent, dependent on the ability of the residents to use the lake for these activities. Metro needs to keep swimming and small boat dock areas weed free for park users, and all stakeholders are concerned with overall water quality issues.

Management Goal

The overarching goal of the Blue Lake Integrated Aquatic Vegetation Management Plan is to control nuisance aquatic vegetation so that human recreational and aesthetic use of the lake is facilitated, acceptable water quality conditions are maintained, and natural functioning of lake aquatic systems is not impaired.

The management strategy for the lake should be adaptive. That is, it should be a process which integrates the lessons learned from outcomes of previous management activities into its current ones. This type of strategy requires periodic monitoring for effectiveness and should be undertaken as a long term process rather than a one time event. The strategy should also have components which aim to educate and inform permanent residents and visitors about how nuisance plants are transported and how to prevent accidental and deliberate introductions of nuisance species.

Public Involvement

Homeowners and residents who live in the immediate area of Blue Lake have a history of community involvement in issues surrounding the lake. In 1997, 70% of those eligible voted to combine three independent water systems into a single, locally controlled People's Utility District. The Interlachen Homeowners Association is active with regular meetings and has contributed financially to the funding of management plan development.

The first public meeting regarding the 2003 Blue Lake IAVMP was held at Gazebo Park on June 11, 2003. Interlachen residents met with Mary Pfauth, Portland State University; Ranei Nomura, Oregon Department of Environmental Quality; Karen Font Williams, Oregon Department of Environmental Quality; and Dan Kromer, Metro Regional Parks and Greenspaces. Ranei Nomura explained the permitting process that would regulate herbicide application to lakes and the current status of permitting in the state while Karen Font-Williams explained the nature of the water quality problems in the lake. Both ODEQ representatives emphasized the need for a management plan for the lake especially as a necessary step in permitting process.

Meeting participants discussed the history of weed treatments in the lake and the success or failure of those treatments. There was general agreement that maintaining high water levels in the lake by pumping in water from City of Portland wells was helpful in controlling the weeds. Many of the homeowners present at the meeting prefer to do chemical treatments of the aquatic weeds in Blue Lake as they have found them to be effective and cost efficient in the past. Mary Pfauth introduced herself and explained that she would be surveying vegetation in the lake over the summer of 2003.

A Steering Committee was formed (Table 1) and its first meeting was held on August 27, 2003. The committee agreed that the results of the summer vegetation survey and a draft Problem Statement and Management Goals would be presented to the public at the October 15, 2003 meeting of the Interlachen Homeowners Association.

Several changes to both the Problem Statement and Management Goals were suggested at the October 15 meeting. Homeowners who live near the west end of the lake wanted to be sure that it was clear that there is a weed problem at the shallow west end of Blue Lake as well as at the more heavily developed east end. Other changes included specific mention of bird watching as a beneficial use and provisions for public education as part of a prevention strategy. A second draft of the Problem Statement and Management Goals was sent to the steering committee via e-mail and print copies were sent to Dennis Meyer to be distributed to Interlachen residents for further comment.

Table 1. Blue Lake IAVMP Steering Committee members

Dennis Meyer	- Interlachen Homeowners Association
Dan Kromer	- Metro Regional Parks & Greenspaces
Jim Lind	- Blue Lake Regional Park
Karen Font Williams	- Oregon Department of Environmental Quality
Mary Pfauth	- Portland State University

Watershed characteristics

Climate

Blue Lake lies in the northern portion of the Willamette Valley which has a modified Mediterranean climate characterized by cool, wet winters and warm, dry summers. Growing seasons in the Willamette Valley are long (150-180 days in the lower portions of the Valley), and moisture is abundant during most of the year, although summer irrigation is common. In a typical year, about half of the total annual precipitation falls from December through February, with smaller amounts in the spring and fall, and very little during summer (Oregon Climate Service).

Extreme temperatures in the Valley are rare. Days with maximum temperatures above 90°F occur only 5-15 times per year, and below zero temperatures occur only about once every 25 years. Mean high temperatures range from the low 80's in the summer to about 40°F in the coldest months, while lows are generally in the low 50's in summer and low 30's in winter (Oregon Climate Service). The prevailing winds in the area, as recorded at Portland International Airport between 1961 and 1990, are from the east from November through March and from the west from April through October (Oregon Climate Service).

Watershed

The watershed of Blue Lake is restricted to the area bounded by Blue Lake Drive and Marine Drive to the north, Interlachen Lane to the west and east and the top of the ridge just north of Interlachen Lane to the south (Fig. 1). The dike on which Marine Dr. is located was constructed in 1938-1941 by the U.S. Army Corps of Engineers. Federal Emergency Management Agency maps show that the lake and adjacent lands are technically within the 10- year floodplain of the Columbia River however, the dike effectively isolates the area from the floodwaters of the Columbia River. The total area of the watershed is 128 acres (51.8 hectares), of which Blue Lake Regional Park comprises 101 acres (40.9 hectares) with the remainder in private ownership. The lands within the watershed have all been developed as residential or recreational use areas.

Blue Lake has no natural surface inlets and its total influx of water is due to precipitation directly on the lake, surface runoff from the surrounding areas, and groundwater seepage through the lake bottom (Beak ,1983) Surface runoff from Marine Dr., which is situated on top of the dike, drains into a ditch at the base of the south face of the dike. Multnomah County Drainage District maps show toe drains (clay drainage pipes installed at the base of a slope) along some portions of the dike's south face, however none are shown in the section between Interlachen Lane and NE 223rd Ave. (D. Hendricks, Multnomah County Drainage District, pers. comm. 2003). There are three small ponds located immediately north of the lake at the far west end. The ponds are interconnected with each other and Blue Lake via culverts and water can flow into or out of the lake depending on water levels.

Lake outflow can be controlled by a concrete weir located in Salmon Creek immediately to the north of Blue Lake Dr. at the east end of Blue Lake (Fig. 1). Water can be released from the lake through the weir and channeled under 223rd Ave., north along the east face of an earthen dike, and into the Columbia River, which is less than a half mile away due north.

Blue Lake Regional Park is a developed recreational area and features food concessions, a small boat rental concession, a swimming beach, tennis courts, an archery range, picnic shelters for large groups, play grounds and play structures, and public rest rooms. There is a boat ramp east of the swimming beach which is open to the public only during the off season (October through April). The park is landscaped with large, level, grassy areas and numerous plantings of shrubs and trees although there are no forested areas per se.

Lake morphometry and hydrogeology

Morphometry

Blue Lake is a 61 acre (24.7 hectares) natural lake created by the regular flooding and erosional forces of the ancestral Columbia River. The river lies directly north of the lake and, while there is no surface flow from the river into Blue Lake, the Columbia River stage affects water levels in the lake. Blue Lake lies at an elevation of 14 ft. (4.3 m) above sea level and is situated 3 miles northwest of Troutdale and 11 miles east of the city center of Portland (Fig.2). Blue Lake Regional Park borders the north and northwest shores of the lake and the subdivision of Interlachen occupies the remainder of the shoreline (Fig. 1). The lake is 0.9 mi (1.4 km) on its east-west axis and 0.12 mi (0.2 km) on its north-south axis. Its maximum depth is 24 ft (7.3 m) with the deepest part of the lake located approximately mid-lake across from the swimming area of the park (Fig. 1, 3). Nearly half (46%) of the lake is 10 ft (3 m) or less in depth providing approximately

Figure 1. Aerial photo of Blue Lake, OR in 2003. Courtesy of Multnomah County Transportation Division.

28 acres (11.4 hectares) of lake bottom potentially suitable for macrophyte colonization (Johnson, et al, 1985). The shoreline of Blue Lake is 2 miles (3.2 km) in length and is free of small embayments. The most striking physical feature of the lake is the sandstone ridge which forms its southern shore and on which private residences have been built. This ridge also forms the southern boundary of the watershed which drains into Blue Lake.

Figure 2. Location of Blue Lake in relation to the Columbia River and Portland, OR

Hydrogeology

The hydrology of the lake and its watershed were described in a series of reports made by Beak Consultants, Inc. (Beak Consultants 1979; Beak Consultants 1983) the Atlas of Oregon Lakes (Johnson, Petersen et al. 1985) and Woodward Clyde Consultants (1994). The following summary information was taken from these sources and sources cited therein.

The Blue Lake basin is underlain by several geologic layers which were laid down at different times and have different compositions. The oldest sedimentary layer is the Sandy River Mudstone deposit composed primarily of clay and silt. Sand and gravel form the uppermost layer of the Sandy River Mudstone. This layer provides abundant groundwater and is commonly referred to as the Sand and Gravel Aquifer (SGA). The overlying sandstone of the Troutdale Formation also serves as a regional aquifer, the Troutdale Sandstone Aquifer (TSA).

Geologically recent deposits of sand and gravel (Blue Lake Gravel) underlie the northern portion of the lake, where an ancestral Columbia or Sandy River has eroded away the Troutdale sandstone (Willis, 1978; Hartford and McFarland, 1989). Wells in Blue Lake Gravels tap the Blue Lake Aquifer (BLA). These aquifers have been used as a water source by both the City of Portland Water Bureau and private citizens which have drilled numerous wells in the immediate area. The Interlachen P.U.D. obtains all its drinking water from such wells and the City of Portland has developed an extensive well field in the area to supplement the Bull Run watershed (Hofstetter, 1984).

Because there are no streams entering Blue Lake, input from other sources such as precipitation, surface runoff, and groundwater are of relatively greater importance than they would otherwise be. Beak (1983) found that groundwater seeps into Blue Lake when Columbia River water levels exceed that of the lake. The relative pressures exerted by the lake and the river on the underlying aquifers are what determine the rate and timing of groundwater seepage into or out of the lake. If Columbia River levels are high relative to the lake, then net flow from aquifers is into the lake via seepage through the lake sediments. Conversely, if lake levels are high relative to the river, then aquifer seepage is reduced (Beak, 1983).

Groundwater from the Portland Well Field has been used in recent years to maintain high lake water levels which can drop more than 30 inches in late summer. Keeping water levels high during the summer has been beneficial to lake users in that aquatic macrophyte growth remains below the water surface. However, the groundwater pumped into the lake is high in nutrients and constitutes an additional nutrient load which could be contributing to the high algae levels in the lake.

Lake water chemistry

Temperature

Water temperature is an important determinant of which aquatic species are present in a lake, their growth and productivity, the rate of chemical reactions taking place in the water column, and the solubility of chemical constituents. Seasonal changes in water temperature determine seasonal changes in communities of aquatic plants and animals. For example, warmer water temperatures during summer speed up the rates of photosynthesis and decomposition. Warm water holds less oxygen than cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures.

The temperature of lake waters varies both diurnally and seasonally. Diurnal temperature variation, in which waters are warmer during the day and cooler at night, is modified by seasonal changes in air temperature. Daily high temperatures will be much higher in summer when air temperatures are highest. Similarly, daily low temperatures will be lowest in winter when air temperatures are lowest.

Different layers within a lake may have different temperatures, especially deeper lakes. In deeper lakes during summer, the surface water is warmed by the sun but the bottom of the lake remains cold, a process called thermal stratification. The upper, warmer and less dense layer that is fairly uniform in temperature is called the epilimnion and the lower, colder and denser layer that is also fairly uniform in temperature is called the hypolimnion. Between the two is a region of sharp temperature change called the thermocline (Fig. 3)

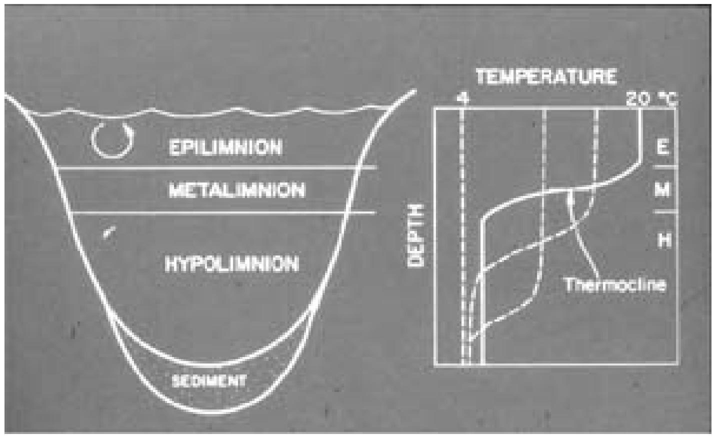


Figure 3. Diagram of thermal stratification in lakes.

Once these layers form, they tend to persist until fall brings cooler air temperatures. When the surface layer of water cools in the fall to about the same temperature as the lower layer of water, the layers mix and the lake is no longer stratified - a process called fall turnover. A similar process - spring turnover - may also occur during the spring as colder surface waters warm to the temperature of bottom waters.

Thermal stratification of a lake results in differences in physical and chemical characteristics between layers and, consequently, profound effects on the species composition and productivity within the layers. The epilimnion is where most of the algal growth occurs because it receives sufficient light for photosynthesis and the hypolimnion is where most of the effects of decomposition, such as oxygen depletion, are observed.

The depth of the thermocline in Blue Lake for both 1982 and 2003 was approximately 3 meters (Figs. 4, 5). Temperatures in Blue Lake in 2003 ranged from between 10°C and 14 °C in spring to summer maximums close to 27°C. Lake temperatures in 1982 were similar although summer maximums were lower by about 2°C.

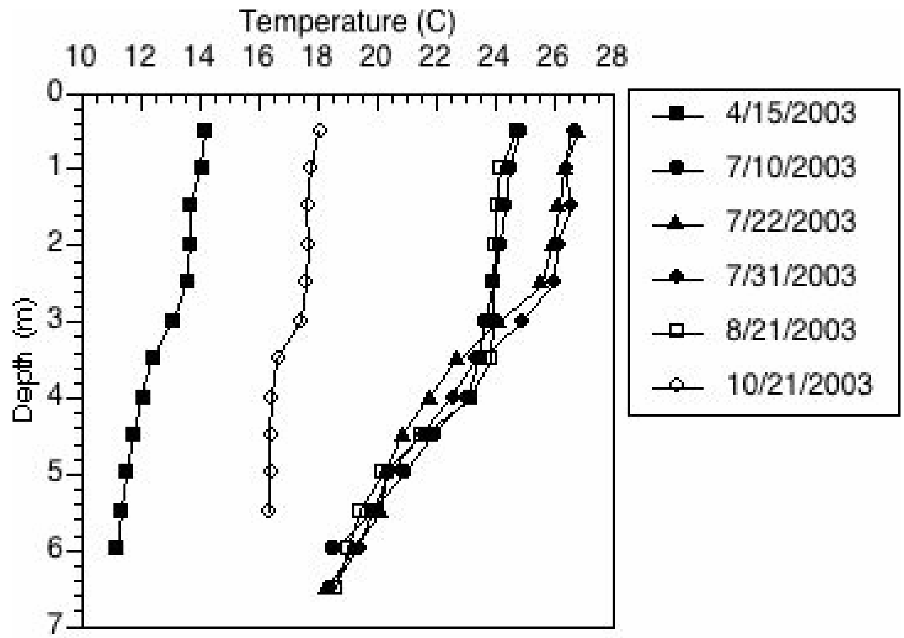


Figure 4. Temperature vs Depth in Blue Lake, OR in 2003. Data from ODEQ.

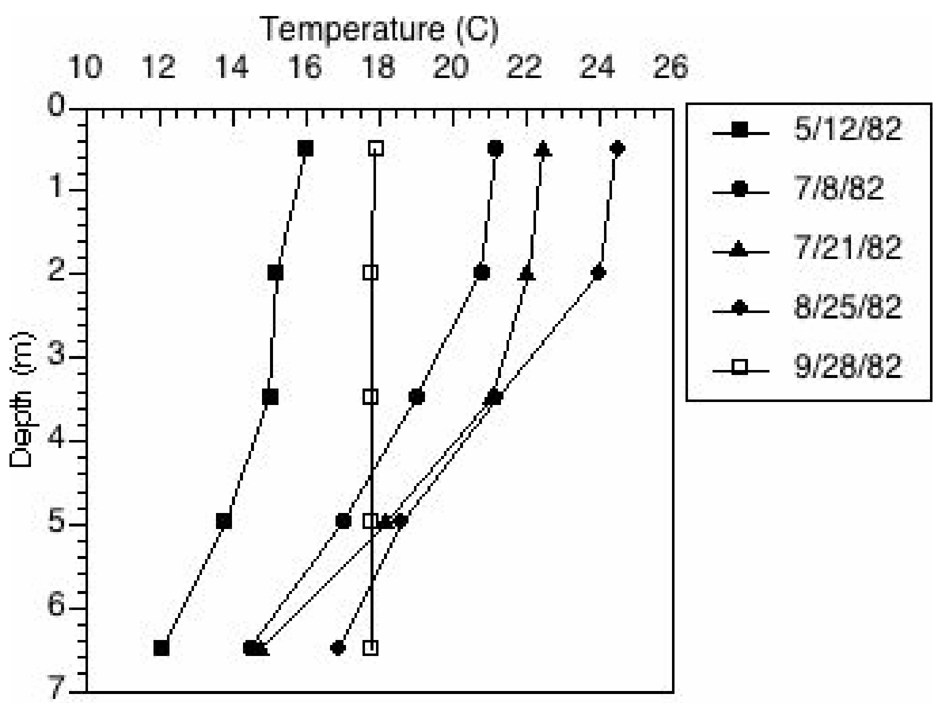


Figure 5. Temperature vs Depth in Blue Lake, OR in 1982. Data from Beak (1983).

pH

The pH of a solution is a measure of the concentration of hydrogen ions in the solution. The pH scale ranges from 0 to 14 with a pH of 7 considered neutral, values less than 7 considered acidic, and values greater than 7 considered basic.

The pH scale is logarithmic so a solution having a pH of 6 is ten times more acidic than a solution having a pH of 7. The pH of a lake is a function of the geology of the watershed and biological activity in the lake. In most freshwater systems, pH is determined by the carbonate (CO_2 – HCO_2^- - HCO_3^-) system.

Changes in pH occur when the concentration of carbon dioxide (CO_2) in the system changes. Photosynthesis and respiration are two major processes which affect the amount of CO_2 dissolved in the water column. The pH may be higher during daylight hours and during the growing season when photosynthesis is at a maximum. Respiration and decomposition result in lower pH.

Lakes are able to resist changes in pH due to the presence of chemical constituents which buffer major pH changes. Small changes in pH may not directly impact aquatic organisms however, the solubility and availability of nutrients and other substances such as toxic metals are directly influenced by these changes. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

The pH of the Blue Lake hypolimnion in 2003 varied between 6.7 and 7.5. Epilimnion pH values were below 8.5 in April and October, but were consistently higher than that in July and August. July and August data from 1982 showed increases in pH similar to those in 2003 however, the maximum value in 1982 was 9 and the maximum in 2003 was 9.5. The 2003 data displayed a sharp difference in pH between the epilimnion and hypolimnion in July and August. The epilimnion was approximately two full pH units higher (i.e., 100 times less acidic) than the hypolimnion with the transition occurring between three and four meters deep.

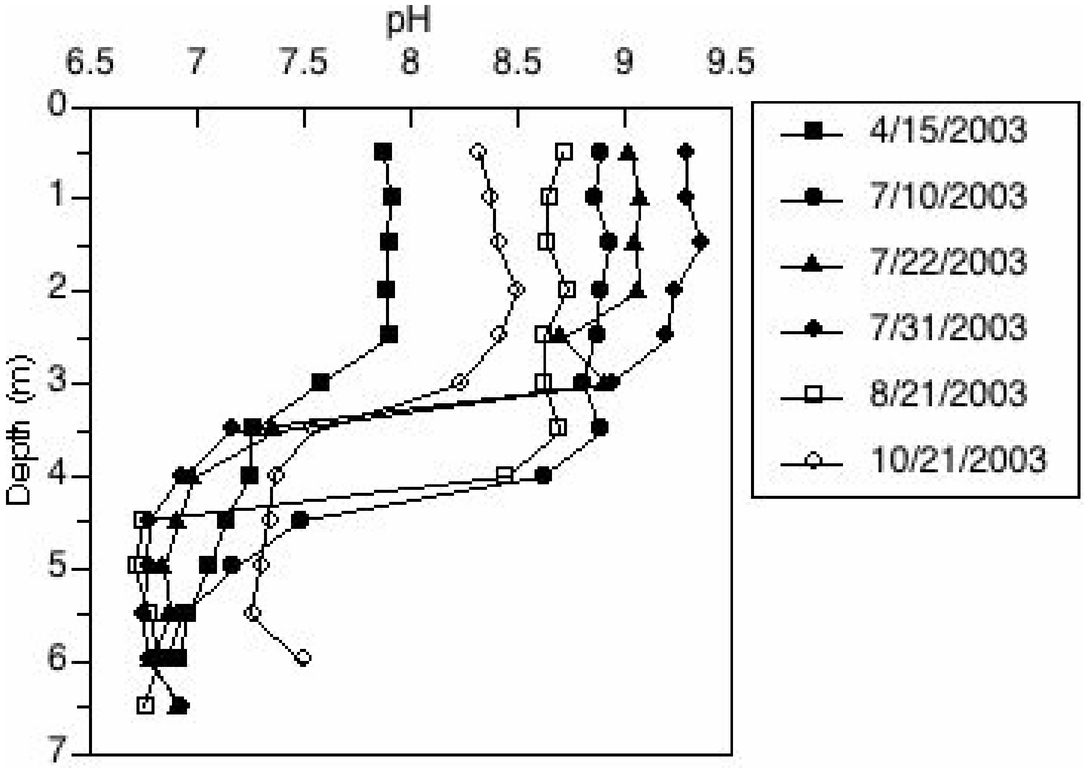


Figure 6. pH vs Depth in Blue Lake, OR, in 2003. Data from ODEQ.

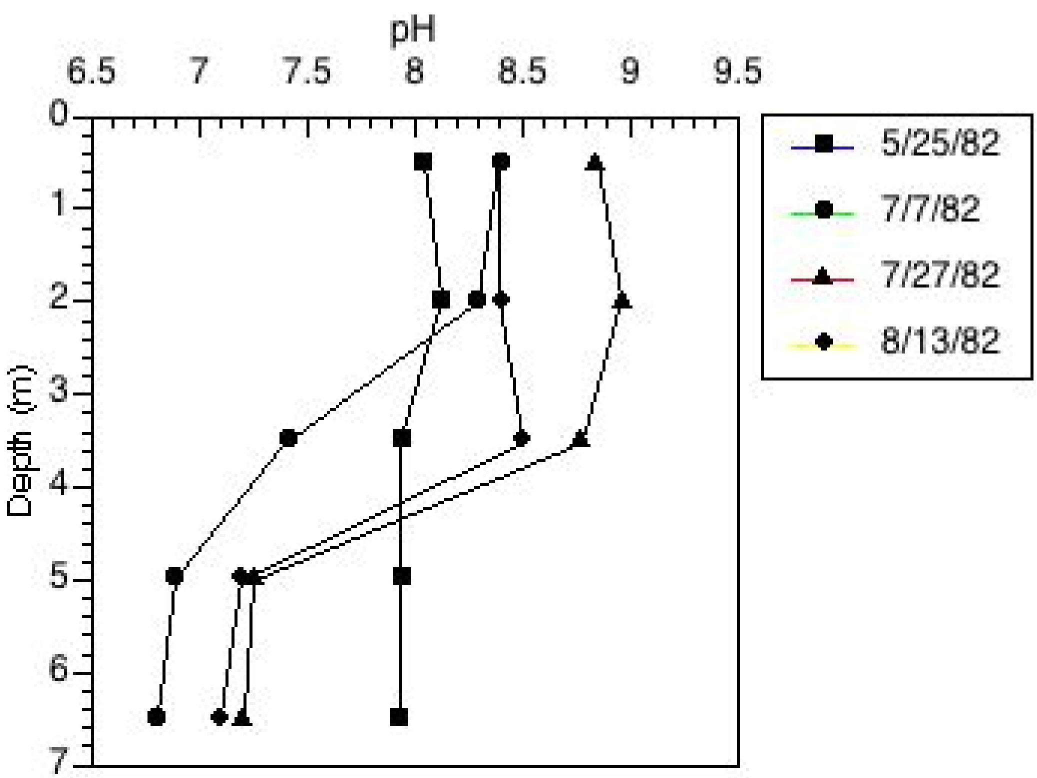


Figure 7. pH vs Depth in Blue Lake, OR in 1982. Data from Beak, 1983.

Dissolved oxygen

Dissolved oxygen (DO) is critical for the survival of many aquatic organisms and is also needed for many chemical reactions that are important to lake functioning. Sources of oxygen in lakes include diffusion at the interface between the air and the water surface, input from streams and precipitation, and photosynthesis.

Oxygen concentrations are much higher in air (about 21%) than in water (less than 1%). Where the air and water meet, the difference in oxygen concentrations causes oxygen molecules to diffuse from the air into the water. The greater the surface area of water in contact with the air, the more diffusion can occur. Thus, windy conditions which create waves (larger surface area) serve to increase the amount of DO in the water. Rivers and streams also deliver oxygen to lakes, especially if they are turbulent and thus well aerated when they reach the lake. Variation in DO concentration in lakes is also caused by weather and resulting changes to inflowing streams (e.g., higher, more turbulent flow during winter months).

Oxygen is produced during photosynthesis and consumed during respiration and decomposition. Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference alone can account for large daily variations in DO concentrations. During the night, when photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition, DO concentrations steadily decrease. They are lowest just before dawn, when photosynthesis resumes.

The relationship between water temperature and gas saturation also affects DO concentrations. Warmer water becomes saturated more easily with oxygen so, as water becomes warmer, it can hold less and less oxygen. During the summer months or in the warmer top layer of a lake, the total amount of oxygen present may be limited by temperature.

DO concentrations can change with lake depth. Oxygen production occurs in the top portion of a lake, where sunlight drives photosynthesis and is lowest near the bottom of a lake, where sunken organic matter decomposes. This difference can be dramatic especially in deeper, stratified lakes– abundant oxygen near the top but practically none near the bottom. Shallow lakes that are easily mixed by the wind may have fairly constant DO concentrations throughout the water column.

It is more useful to look at the percent saturation of oxygen in a particular water column than just the absolute values of DO. Values above 100% (i.e., oxygen supersaturation) are generally due to the photosynthetic activity of algae and/or aquatic macrophytes (Wetzel, 2001).

Dissolved oxygen measurements in the Blue Lake water column were very similar overall between the two years (Figs. 8-11). Both had DO values in the hypolimnion ranging from 0 mg/L to 6 mg/L and in the epilimnion ranging from 6 mg/L to 12 mg/L. Oxygen saturation values were also similar between the years with 0% to 80% saturation in the hypolimnion and 90 to 140% saturation in the epilimnion. Of particular interest is the DO profile of July 22, 2003. which displays a sharp increase in percent DO saturation to 140% at a depth of three meters (i.e., the thermocline). Values at depths above and below this sample point were about 110%. A pronounced oxygen maximum in the epilimnion such as this is not unusual and was likely caused by high concentrations of algae at that depth (Wetzel, 2001). Chlorophyll *a* data from the same sample depth and date provide additional evidence of high algal production (Table 2). Chlorophyll *a* concentration was 51 µg/L in the metalimnion as compared to 10.9 µg/L in the epilimnion and 13.1 µg/L in the hypolimnion. Even without the photosynthetic activity of phytoplankton, an oxygen maxima is typically present at the metalimnion due to the reduced solubility of oxygen in the warmer epilimnion layer and oxygen consumption in the hypolimnion. Types of phytoplankton that can regulate their buoyancy and are adapted to conditions of low temperature and low light intensity, such as cyanobacteria, are able to exploit the high nutrient concentrations which typically are present in the metalimnion. The high productivity of these organisms results in even higher oxygen levels at that depth.

Table 2. Chlorophyll *a* (µg/L) in Blue Lake, OR in 2003. Data from ODEQ

Depth	4/15/2003	7/10/2003	7/22/2003	7/31/2003	8/21/2003
0.5	3.9				
1		9.4	10.9	18	12
2	4.1			22	12
2.5		11			
3	5		51		
3.5				16.5	
4			13.1		
4.5		17			27

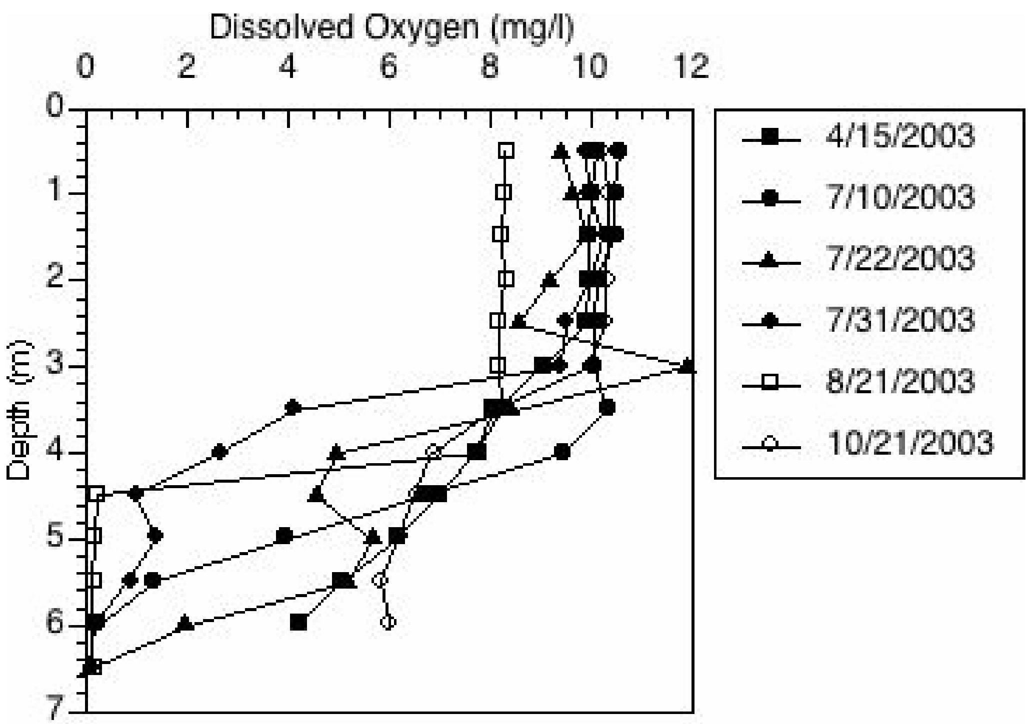


Figure 8. Dissolved oxygen vs Depth in Blue Lake, OR in 2003. Data from ODEQ.

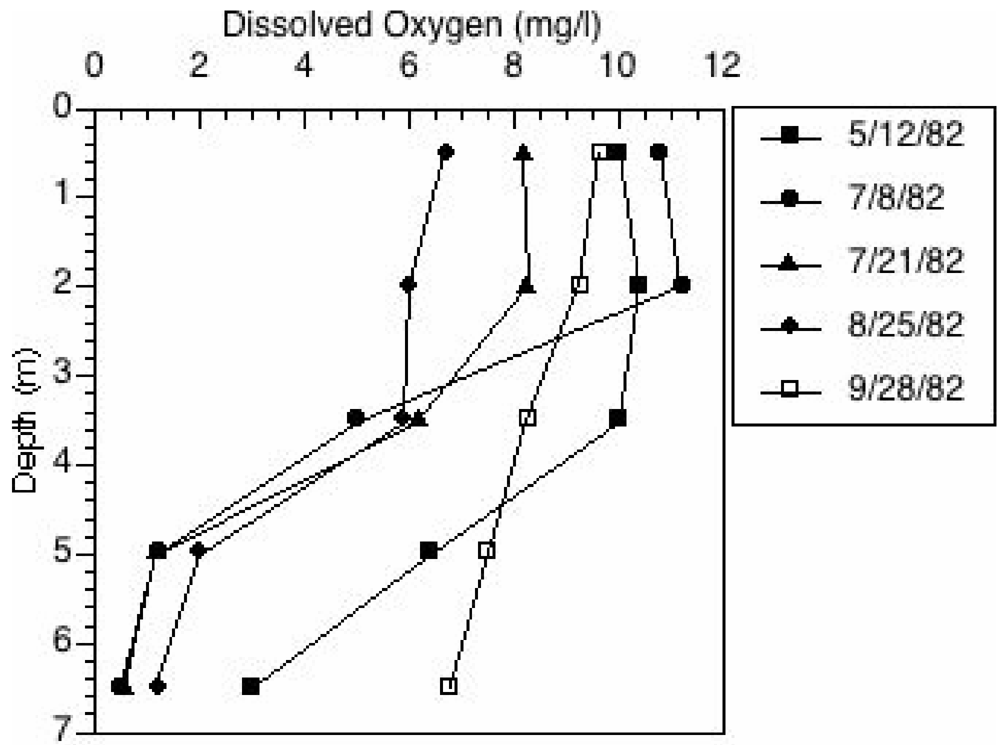


Figure 9. Dissolved oxygen vs Depth in Blue Lake, OR in 1982. Data from Beak, 1983.

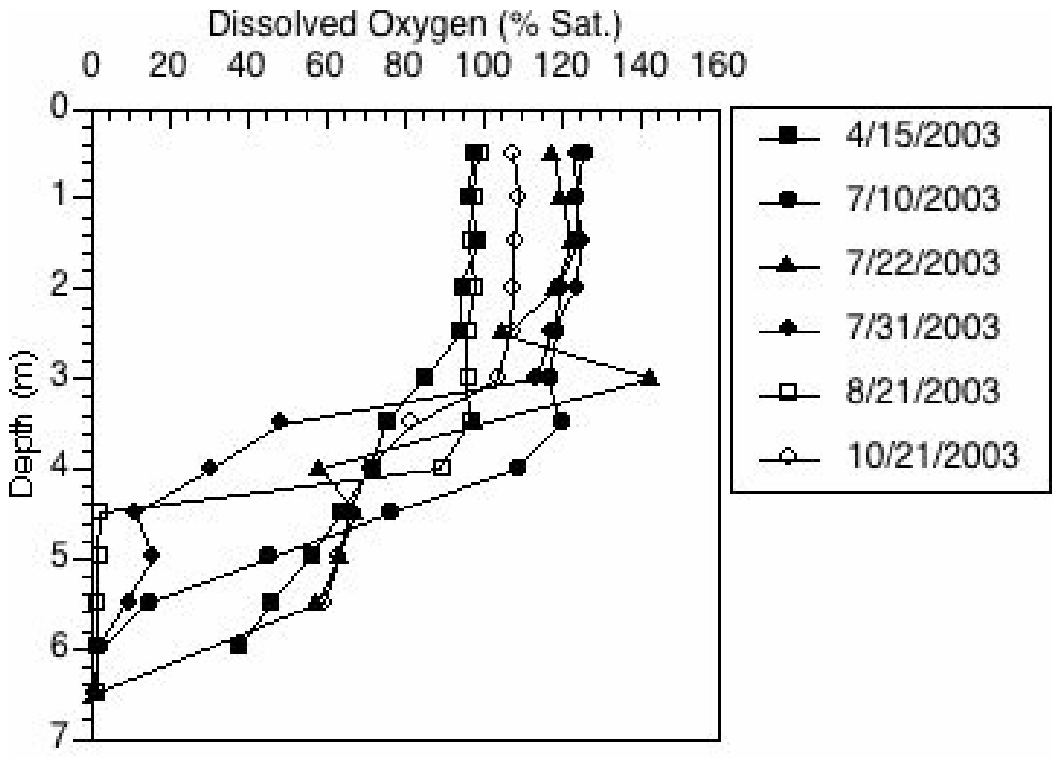


Figure 10. Oxygen saturation vs Depth in Blue Lake, OR in 2003. Data from ODEQ.

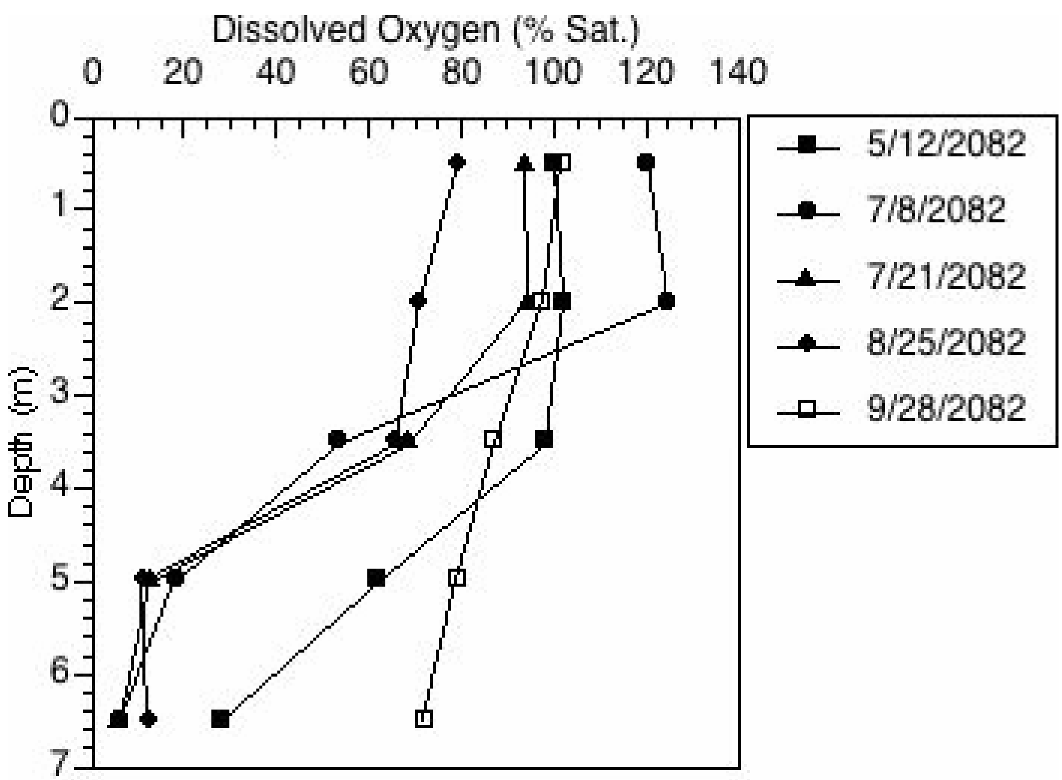


Figure 11. Oxygen saturation vs Depth in Blue Lake, OR in 1982. Data from Beak (1983).

Nutrients

Nitrogen and phosphorus are the nutrients that are most commonly the major determinants of the algal productivity of a lake. Both elements are present in lake water and sediments in different chemical forms. For example, nitrogen is present in nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3). The different forms are interconvertible depending on pH, temperature, oxygen concentration, and biological activity. Nitrogen and phosphorus are also present in the organisms inhabiting the lake.

The nitrogen to phosphorus ratio (N:P) is a measure of the relative amounts of nitrogen and phosphorus in a water column. This ratio is used to characterize a waterbody as either nitrogen limited or phosphorus limited. Lakes having ratios less than 7 are considered to be nitrogen limited, those with ratios greater than 10 are considered to be phosphorus limited. Nitrogen and phosporus ratios with values between 7 and 10 are indicative of a waterbody in which both elements are co-limiting (Smith, 1982).

Table 3. N:P in Blue Lake, OR

	1982	2003
JULY	21.8	17.9
AUGUST	15.3	20

The nitrogen to phosphorus ratio in Blue Lake was calculated using total nitrogen (inorganic + organic) and total phosphorus - the Redfield ratio (Wetzel, 2001). Data from the epilimnion were averaged for July and August 1982 and 2003 (Table 3). Ratios for 1982 differ from those reported in Beak (1983) because Beak used the ratio of total soluble inorganic nitrogen to total phosphorus. Ratios for both years indicate that Blue Lake is phosphorus limited during the summer months. That is, nitrogen is relatively abundant and phosphorus is relatively scarce. Phosphorus inputs to Blue Lake during the summer when N:P is high would favor increased phytoplankton productivity.

It is essential to limit phosphorus loading in the lake if algal productivity is to be limited. Total phosphorus in Blue Lake ranged from 0.03 mg/L to 0.08 mg/L in the mid to upper layers of the water column and as high as 0.26 mg/L near the sediments. Total phosphorus in the groundwater that was pumped into Blue Lake was 0.12 mg/L (C. Ireland, City of Portland, pers. comm..) – much higher than levels already present in the bulk of the water column.

Lake ecosystems

Alternate stable states

Shallow lake ecosystems with moderate levels of nutrient loading, such as Blue Lake, typically exist in one of two stable states (Scheffer et al, 1993; Scheffer, 1998; Scheffer and Jeppesen, 1998). A lake having abundant macrophytes present is often clear and one with few or no macrophytes present is often turbid and dominated by phytoplankton. Aquatic macrophytes and phytoplankton in lakes compete for some of the same limited resources. Both require light, nutrients, and oxygen and both require them in forms that are available for uptake.

When macrophytes are abundant in a lake, water movement due to wind is reduced and suspended sediments in the water column settle to the lake bottom. Macrophytes provide habitat for organisms which graze on phytoplankton, compete with phytoplankton for nutrients, and intercept light. Water clarity is improved due to the reduced amount of sediment and reduced phytoplankton numbers in the water column.

A phytoplankton dominated lake is typically turbid, i.e., having poor water clarity. With no macrophytes to slow wind induced water movement, sediment remains suspended in the water. Without the surface area furnished by macrophytes, surface-associated herbivore numbers are limited and phytoplankton become more abundant. Large amounts of suspended sediment and abundant phytoplankton result in turbid waters.

It is possible that water clarity in Blue Lake could be reduced if all aquatic macrophytes were removed from the lake. Vegetation management in the lake should be directed towards a high level of control for curlyleaf pondweed, an introduced, invasive plant species, and lower levels of control for the native plant species. Managing native aquatic plants species at lower control intensities reduces impacts to organisms such as fish and aquatic invertebrates which rely on them for habitat. This control strategy would also reduce the likelihood of increases in turbidity which could potentially occur if all vegetation were removed.

Trophic state

The trophic state of a lake is a measure of its degree of nutrient enrichment and thus, its productivity, and is based on the fact that algal biomass is primarily determined by nutrient loading rates. Nutrient enrichment of lake waters (eutrophication) can be due to natural causes or it can be accelerated by humans. A trophic state index (TSI) is a numerical rating of a lake which is useful for comparing different lakes and for comparing the same lake at different times. A commonly used TSI is one developed by Carlson (1977) which uses a scale from zero to one hundred (Figure 12). At the low end of the nutrient enrichment scale are ultraoligotrophic lakes with TSI's less than 20 and at the other extreme are hypereutrophic lakes with TSI's greater than 65. Carlson's method can use water clarity (Secchi depth), total phosphorus, chlorophyll *a*, or nitrogen to calculate a TSI.

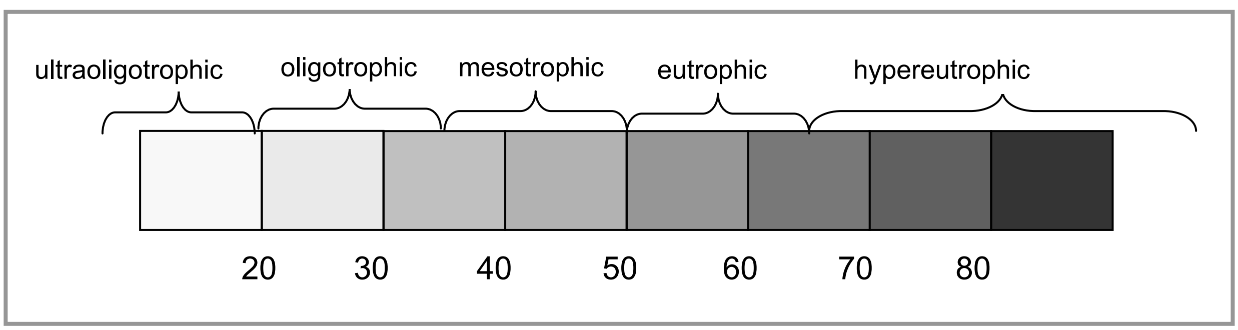


Figure 12. Trophic State Index (TSI) scale. (after Carlson, 1977)

TSI's were calculated for the epilimnion of Blue Lake using Secchi depth, chlorophyll *a*, and phosphorus. Secchi disk, chlorophyll *a*, and total phosphorus data from the productive summer(July, August) period were usedto calculate TSI's. TSI's were between 50 and 70 in 2003 which place the lake in the eutrophic to hypereutrophic category. Carlson's TSI does not include a consideration of rooted aquatic plant productivity in lakes, which can dominate productivity in shallow lakes. Therefore, the calculated TSI may misrepresent the true trophic state of Blue Lake.

Phytoplankton

Phytoplankton is a term which encompasses several different types of photosynthetic, microscopic organisms which inhabit fresh, brackish, and saline waters of the world. Microscopic algae, cyanobacteria (also known as blue-green algae), diatoms, euglenas, and dinoflagellates are included in this group of organisms. Phytoplankton are a normal component of lake ecosystems. Their abundance and productivity within the water column vary with the season, with their location in the water column, and with water chemistry.

Cyanobacteria can regulate their buoyancy, which allows them to exploit gradients in light and nutrients in lakes. Cyanobacteria are normally present in Blue Lake and their populations display seasonal variations in abundance. Cyanobacteria were the dominant forms of phytoplankton in September and October 1981 (Beak, 1983), in May through September 1982 (Beak, 1983), in August and September 2002, and in July through September 2003 (Fig. 13).

Phytoplankton or algal "blooms" are a phenomenon in which the numbers and density of these organisms increase greatly in a short period of time, typically weeks. Blooms can occur sub-surface or, when they are formed by cyanobacteria, they may form thick scums on the surface. Blooms can cause water quality problems such as elevated pH, and low DO concentrations when the bloom subsides. Cyanobacteria blooms can produce unpleasant odors, and, in some cases, toxic by-products.

Anabaena, Aphanizomenon, and *Microcystis are* common bloom-forming species of cyanobacteria. *Anabaena* and *Aphanizomenon are* nitrogen fixers and would be favored under conditions of nitrogen limitation. *Microcystis* is not able to fix atmospheric nitrogen and its growth is dependent on sufficient levels of nitrogen and phosphorus. The biovolume of the mid-September 2003 bloom in Blue Lake was composed almost entirely of two cyanobacteria: *Microcystis aeruginosa* (15.8%) and *Anabaena planctonica* (79.7%). Both *Microcystis* and *Anabaena* have been known to produce the liver toxin microcystin, although different strains of the same species may be particularly high producers of the toxin. Some cyanobacteria, A*nabaena* and *Aphanizomenon* species for example, may also produce anatoxin-*a* which is a nerve toxin. Analysis of a sample of visible algal scum collected on September 29, 2003 did not yield detectable concentrations of this toxin (K. Font Williams, ODEQ, pers. comm.).

Accurate prediction of toxic algal blooms is not yet possible due to complex interactions within a water column that are not completely understood. Nonetheless, there are some factorsthat appear to be correlated with these blooms: stable water columns, high nutrient loading rates, and high temperatures favor cyanobacteria. While inputs of groundwater to the lake undoubtedly influence algae populations in general, the available data do not show that groundwater “causes” blooms of cyanobacteria. Phosphorus rich groundwater (N:P≤4.5) was pumped into the lake from July 17 through July 20 when cyanophyte biovolume was already at its maximum (Figure 13).

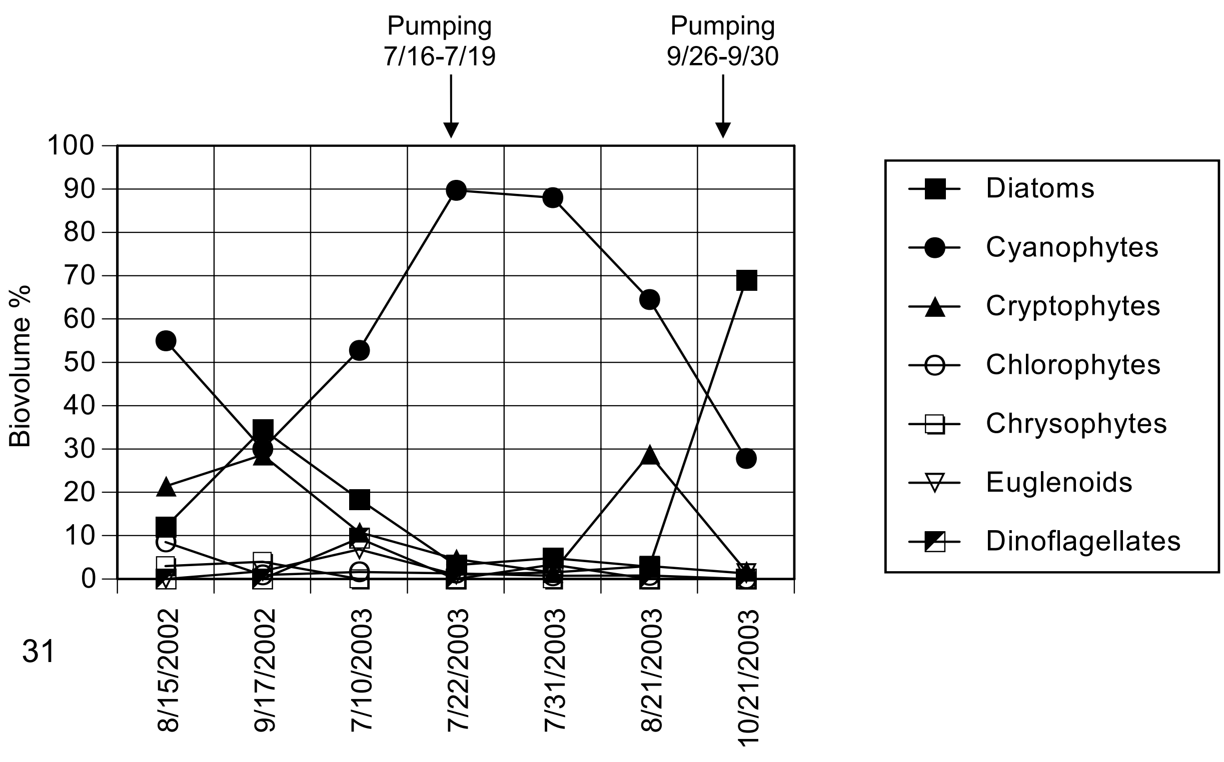


Figure 13. Phytoplankton biovolumes in Blue Lake, OR in 2002 and 2003. Data from ODEQ.

Conclusions

Blue Lake is a eutrophic lake having high algal productivity, especially in mid to late summer. In general, the lake is phosphorus limited which means that phosphorus inputs to the lake must be reduced if the severity of algal blooms is to be reduced. The hydrology of the lake and the surrounding area is complex and not well understood, although it is known that groundwater seepage through the lake bottom is one of the major inputs to the lake. Groundwater pumped into the lake at the surface from City of Portland wells #13 and #19 has been used to supplement lake levels later in the summer. The groundwater is high in phosphorus (0.12 mg/L) and could be indirectly exacerbating pH problems by driving up algal productivity.

If pumping is to be continued, then the water should have a phosphorus concentration no higher than 0.02 mg/L. Other potential sources of low nutrient water are the Bull Run reservoir and the Columbia River. The City of Portland does have the ability to obtain Bull Run water however it does not have the ability to dechlorinate that water (C. Ireland, Portland Water Bureau, pers. comm.). Both of these options would be expensive and would entail considerable engineering. Further discussion of these two options is beyond the scope of this management plan.

Note:Water quality data collected by ODEQ in 2002 and 2003 are tabulated d in Appendix F. Values and trends for both years are similar, only 2003 data were presented graphically in the body of the report.

Vegetation Survey

Effective management of aquatic, nuisance plants requires accurate information about species present in the management area, their relative abundance, and their locations within the waterbody. Different species may respond differently to particular management practices so it is important to know what species are present. Plant species vary in their susceptibility to different herbicides, biocontrol agents and the timing of control activities. For example, the most effective chemical control of curlyleaf pondweed is achieved at the start of its annual growth cycle rather than at peak biomass.

Lakewide aquatic macrophyte surveys were done twice in 2003: once in July and again in September. A set of one hundred and sixty GPS coordinates were randomly selected from a grid comprising five-meter squares which was overlaid on the lake surface. The same GPS coordinates were sampled on each date. Data collected include plant species identifications and estimates of plant species abundance. Voucher specimens were deposited in the PSU herbarium. Profiles of the dominant plant species are found in Appendix A. The data collected in the vegetation surveys was used to generate a vegetation map of the lake (Figure 3). The vegetation map is intended to show areas of plant species dominance and does not reflect small, isolated patches of individual species within the lake.

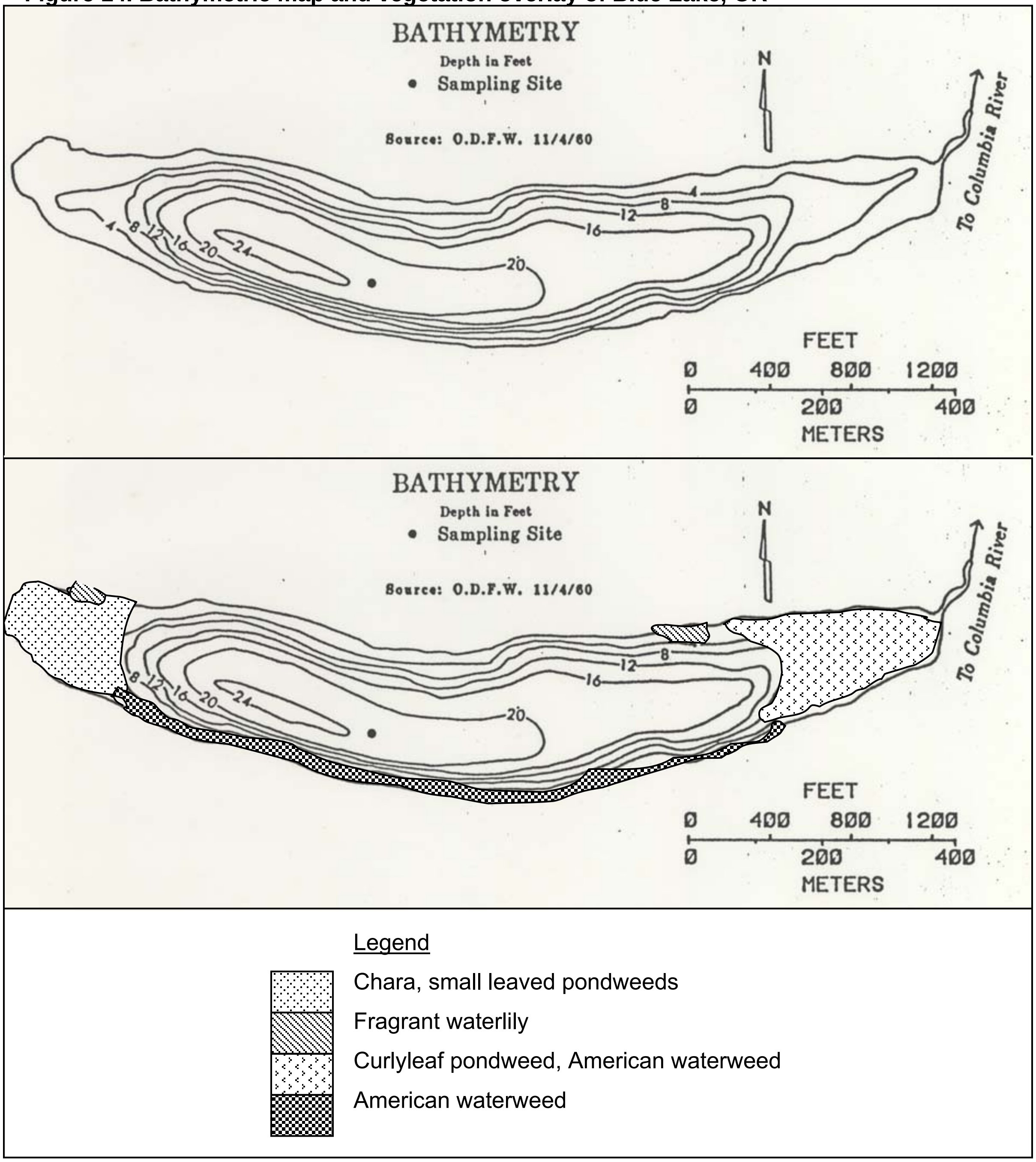
A total of five aquatic plant species was found in the surveys none of which are rare, threatened, or sensitive species. Appendix E contains vegetation survey data. Other Oregon lakes with less disturbed plant communities contain a dozen or more species (Pfauth & Sytsma, 2004). The dominant, submersed, aquatic plants in the lake are curlyleaf pondweed (*Potamogeton crispus*) and American waterweed (*Elodea canadensis*) in the east end; American waterweed along the south shore; and muskgrass (*Chara*) and thin-leaved pondweeds (*P. foliosus, P. pectinatus*) in the west end. The abundance of curlyleaf pondweed is underestimated because of the timing of the survey. This species achieves maximum biomass in late spring/early summer (i.e., before July), after which plants cease growth and decay. Blue Lake Regional Park maintenance personnel have observed that spring regrowth of the curlyleaf pondweed typically begins no later than March and peaks in May (D. Vermaas, Blue Lake Regional Park, pers. comm.). The extent of the curlyleaf pondweed at its maximum growth stage is probably much greater than the July and September survey results indicate.

Colonies of fragrant waterlily (a floating leaved species) grow along both the east and west ends of the north shore and do not pose much of a nuisance so far. The shallow waters of the swimming beach do not support much plant life. This is probably due partly to extensive dredging and recontouring work which removed existing vegetation from the sediments. The bottom of the swim beach was lined with sand as well and, since aquatic plants generally prefer a siltier substrate, it is likely that the new substrate suppressed aquatic plant growth. Interlachen residents have also noticed that aquatic plant growth is reduced in areas in which they deposit sand (commonly next to their boat docks).

Only fragments of the introduced, invasive Eurasian watermilfoil were found in this survey - a significant change from past years when it was the dominant species in the lake. It is possible that Eurasian watermilfoil is still present in the lake at very low levels or that the fragments were transported into the lake on a boat or waterfowl. Curlyleaf pondweed is an introduced, invasive species as is fragrant waterlily. American waterweed, *Chara* and the thin leaved pondweeds are native plant species which are common in the region.

The maximum depth at which aquatic plants were found was eight feet. A comparison of the bathymetric map with the vegetation map (Fig. 3) shows that most of the areas of the lake which are less than ten feet deep have been colonized to some extent by aquatic plants. The significant exception is the swimming beach area on the north shore which has a sandy bottom.

Figure 14. Bathymetric map and vegetation overlay of Blue Lake, OR



Aquatic Plant Management Techniques

A variety of techniques are available for aquatic plant management, including physical, mechanical, biological, and chemical control methods. An integrated approach to aquatic vegetation management that produces the desired outcome and minimizes the possibility of unintended consequences requires consideration of the problem species, the management objective, and the possible impacts of management activities. Best management practices currently available for aquatic macrophytes have recently been published by the Aquatic Ecosystems Restoration Foundation (2003). Information on management techniques contained in the following sections was drawn from that report as well as from the Washington Department of Ecology (2003).

Required Intensity of Control

When managing aquatic weeds, it is important to keep in mind the presence of native plants and animal species that may be harmed by the method of control used. This becomes important when there are threatened or endangered species present. Several of the weed management options available indiscriminately remove all plant species. This may be appropriate in irrigation canals or storage reservoirs where no vegetation is desired, but native vegetation is desirable in a natural system. To reduce impact on native vegetation and animal life it is necessary to decide the proper level of control for specific use areas in the lake. The options are no control, low level control, and high level control.

No Control

In some cases it may be necessary to leave special habitat areas within the lake untouched. This is especially true when the control techniques available may have a net negative impact on habitat quality. All salmonid-bearing waters described in the Oregon Plan Salmon Restoration Initiative should be treated with caution. If management techniques degrade the function of shoreline wildlife areas, e.g., nesting and forage sites for waterfowl and other animals, no control may be possible. Native plant beds that function as fish spawning sites should be preserved or subjected to minimal treatment. In some cases, the presence of native plants may have aesthetic value to the surrounding community.

Low-level Control

Low level control usually involves a partial removal of vegetation. For instance, in lakes where a warm-water fishery is important, using mechanical means to develop fish lanes through vegetation can be quite valuable. Low-intensity control efforts are also important in shoreline treatments where emergent vegetation is to be protected. Low-level control maximizes enjoyment of a water body while minimizing plant removal. A benefit of low-level control using mechanical means is the low treatment cost per acre because only patches of vegetation are being removed. The disposal cost of the removed material is much less than if the entire plant population were removed.

High-level Control

The occurrence of certain aquatic plant growth situations may require aggressive control. The presence of invasive non-native plants may justify aggressive measures to remove plants, especially where critical salmonid habitat may be jeopardized. It may be necessary to clear all vegetation from swimming or wading areas for safety reasons. Other areas requiring intensive removal may include areas around docks or boat ramps. It is important to note that the latter two examples describe small-scale, localized treatments. Lake-wide control efforts affecting 100 percent of aquatic plants are not appropriate, except in lakes where invasive, non-native plants have been identified.

Control Level for Blue Lake

The management goal for Blue Lake is to facilitate human uses of the lake and to improve water quality. Blue Lake does not contain salmonids but it does contain several types of warm water fish which have been introduced over the years as game fish. It has little emergent vegetation surrounding it and aquatic plant species diversity within the lake is low. Nuisance aquatic plant species, both native and introduced, are abundant in the shallow parts of the lake. Neither the “no control” nor the “low control” option is appropriate in this lake. A modified, high-level of control is appropriate for the management goal in Blue Lake. The management goal will require a high-level of control for both the east and west ends of the lake as well as the areas around the private boat docks along the south shore. The fragrant water lily colonies along the north shore are a lesser nuisance and could be managed at a lower intensity. There is some aquatic vegetation growing in the small boat concession area, however, it is not nearly as abundant as that in other areas of the lake and does not appear to cause significant problems.

Physical Controls

Physical control methods consist of hand pulling or cutting, bottom barriers, and water level manipulation (Table 4). Hand pulling and cutting are more appropriate for small areas in shallow water. Bottom barriers can be used around docks and in swimming areas, but are impractical and not cost-effective when large areas are to be treated. Water level draw-down is used to control plants by drying them and exposing them to potentially freezing temperatures. These control methods are non-selective for the most part in that they impact native and non-native, desirable and undesirable species indiscriminately.

Permits

The U.S. Army Corps of Engineers (USACE) regulates fill placed in non-navigable wetlands and waterways under Section 404 of the U.S. Clean Water

Act, and regulates all structures and work in, or affecting, navigable waters of Section 10 of the Rivers and Harbors Act. Permits are required for these types of activities, which may include some types of aquatic weed control methods. Each situation must be evaluated by USACE and a permit may be required depending on the site. Some activities may qualify for a Nationwide permit, which is a streamlined, no cost permit typically issued for activities that take place often

Oregon Division of State Lands (DSL) regulates the bottom of lakes, and Oregon's Removal-Fill law (ORS 196.795-990) requires individuals and groups who plan to remove or fill material in waters of the state to obtain a permit from DSL. Permits or General Authorizations (see description at end) are required for: (1) projects requiring the removal or fill of 50 cubic yards or more of material in waters of the state or (2) the removal or fill of **any quantity of material,** in a water body designated as Essential Salmon Habitat. The law does not apply if your work in waters of the state is for the fill or removal of less than 50 cubic yards, except in essential indigenous anadromous salmonid habitat and scenic waterways (ORS 196.810(b)).

For certain types of activities, DSL issues a streamlined type of permit called a General Authorization. The "letter of authorization" generally covers smaller projects, such as the General Authorization for Minimal Disturbances Activities (less than two cubic yards) within Essential Salmon Habitat. In order to qualify for one of these General Authorizations, your project must meet **all** the qualifying criteria and you must agree to abide by **all** conditions specified. Many projects that require a DSL removal-fill permit also will require a federal permit from the USACE. DSL and USACE use a joint permit application form, so only one application will need to be filled out to obtain both permits. **However, you must send a copy of the application to both agencies.**

For two types of General Authorization, Fish Habitat Enhancement and Wetland Enhancement, DSL uses a customized application form. These customized forms are not recognized by the USACE, so applicants must still prepare the standard Removal-Fill form for the USACE. Each agency reviews the form and issues separate permits that may have different requirements. Either agency may require a permit when the other does not. When you send in your completed permit application to USACE, they will notify you if you need USACE approval of the permit in addition to state approval.

Since Blue Lake is not known to contain endangered species (e.g. salmonids), a NOAA Fisheries consultation is not needed.

Some aquatic plant management options, such as diver operated suction harvesting, may create turbidity. The existing turbidity rule in the Oregon Department of Environmental Quality (DEQ) Water Quality Program division 340-41 refers to a maximum increase in turbidity of 10 percent relative to upstream water. However, this rule refers specifically to streams and not lakes. DEQ is currently developing a new turbidity standard that addresses a wider range of circumstances with more specific endpoints. "Ponded systems," such as lakes, are addressed in the draft standard language. The new draft rule states that there is a limited allowable increase of turbidity in terms of NTUs (nephelometric turbidity units) and a limited percent-increase in turbidity within a specified distance. These draft limits will approximate the 10 percent rule currently in place for streams, however specifics are not available as the standard is still in draft. A permit may be required for those methods that stir up sediments and create turbidity such as diver operated harvesting. Stakeholders should contact the TMDL Coordinator prior to beginning any work. Precautions should always be taken to limit the creation of turbidity during the above listed actions, such as using a sediment curtain to limit the spread of the turbid water.

The Oregon Department of Fish and Wildlife stocks trout into Blue Lake and should be notified of plant management activities in the lake. They would appreciate any measures taken to avoid harming these fish such as coordinating management actions with their stocking schedule.

Landowners and lake managers should contact the USACE, the DSL Resource Coordinator for Multnomah County, and the Multnomah County Land Use Planning Department prior to placing any structures or performing other management activities in the lake. See Appendix C for agency contact information.

Hand pulling/raking

Pulling or raking aquatic plants is practical in small areas. This technique is especially effective when used in conjunction with bottom barriers. Using this method, existing macrophytes can be cleared from a small area before bottom barriers are installed. New plants arising from plant fragments (species dependent) or seeds can take root on top of the barriers, and sediment gradually builds up on them. Pulling and raking are an inexpensive way to keep bottom barriers free of plant growth on top of or around the barriers.

Tool requirements are minimal. Almost any type of rake will work although some are more practical than others. There are specialized aquatic weed rakes available which are similar to a landscapers rake. Both types are lightweight and have a broad head. Aquatic weed rakes have a hole in the end of the handle through which a rope can be fastened so that the rake can be easily retrieved from the water.

Freshly harvested biomass is quite heavy due to high water content of the plant tissues and to water clinging to the plant surfaces. Disposal of biomass is easier and less costly if weight and volume are reduced. Allowing harvested plant material to drain excess water and, if possible, to dry down the tissues would greatly reduce the total weight and volume. It would also reduce the amount of physical labor needed to transfer the harvested plants to the disposal site. Residents at some lakes have used old fishing nets to haul plant harvestings. The nets allow water to drain and air to circulate. They also allow for a much larger plant volume to be handled than a wheelbarrow. Harvested biomass can be composted by individuals for later garden use rather than disposing of it in a landfill.

Bottom barriers

Bottom barriers are relatively inexpensive, can be easily built by the average homeowner and are effective in suppressing aquatic plant growth in localized areas such as close to docks. Multnomah County experimented with bottom barriers in Blue Lake in 1982 (Beak, 1983). Ten meter by twenty meter panels made of fiberglass fabric were installed in the old swim area and monitored for milfoil regrowth. Little or no plant growth occurred under the bottom barriers. Those plants that did grow on top of the barriers were due to rooting of floating fragments and illustrated the need for regular maintenance of the barriers.

Bottom barriers should be installed before spring plant regrowth begins. They can be installed later in the growing season, but existing vegetation would then have to be cut back and removed to allow installation of the barriers. Bottom barriers can be left in place all year long but removal and winter storage prolongs their effective life. Removal in late summer or early fall also allows them to be cleaned of accumulated sediment.

A number of different sheet materials will work in this application. In addition to fiberglass, plastic sheeting, burlap, weed suppression cloth (used by landscapers and gardeners), and geotextile fabrics (used in estuarine weed control and in construction applications) can be used with varying degrees of effectiveness and durability. Directions for building bottom barriers, as well as case studies, can be viewed at *http://www.ecy.wa.gov/programs/wq/plants/management/aqua021.html* The fabrication directions have been included in Appendix D along with some sources of weed barrier and geotextile fabrics (Appendix B) to provide a general idea of local price and availability.

Diver harvesting

Diver harvesting is a method whereby SCUBA divers use hoses attached to small suction dredges to suck plant material from the waterbody. Divers experienced in aquatic macrophyte removal are able to pull target plants with little disturbance to the sediments or to non-target plant species. They use the suction hose to get the plant biomass to the surface and onto a barge for transport to shore and subsequent upland disposal. The benefit of using diver operated suction is the total containment of plant fragments that are generated. Very little sediment is collected with diver harvesting of isolated plants.

Diver harvesting is not generally practical or economically feasible on a whole-lake scale. Costs depend on the size and depth of the target area and the density of the target plant species. Divers experienced in aquatic plant removal in the region charge a minimum of one to two dollars per square foot. A preliminary dive would have to be done in order to obtain an accurate estimate of the time and costs involved (see Appendix B for diver contacts). Diver harvesting is useful as a means of clearing out localized areas in need of high levels of control and as a follow-up treatment to remove small, isolated patches of nuisance aquatic plants which have regrown or were missed by earlier control activities. This technique has been used successfully at Silver Lake, Everett, WA (and other lakes in the region) for milfoil control.

If the diver causes disturbance to or removal of 50 cubic yards or more of lake sediment, then a removal fill permit and (potential) mitigation are required by the Oregon DSL and US Army Corps of Engineers. If this method is to be used, then the issue of sediment disturbance or removal needs to be addressed and necessary permits obtained if the situation warrants.

Water level manipulation - drawdown

Drawing down lake water levels exposes aquatic plants and lake sediments to possible freezing and desiccation if done in winter, and to high temperatures and desiccation if done in summer. Freezing can have a dramatic impact on aquatic plants that have no over wintering structures (viable seeds, turions, tubers, or winter buds) such as Eurasian watermilfoil or Brazilian elodea. The same conditions that are detrimental to aquatic plants can also be detrimental to aquatic invertebrates, amphibians, and mammals. If a lake is in an area which experiences regular freezing temperatures and has an existing water control structure then this technique can be a cost effective one. Long term aquatic plant control using drawdown is only achieved if the process is repeated regularly.

Drawdown was used in Blue Lake in winter 1981 as a method of controlling Eurasian watermilfoil. The drawdown resulted in limited success as far as milfoil reduction and significant milfoil regrowth did occur after the lake was refilled. The drawdown caused other, unforeseen problems such as damage to retaining walls and docks, and difficulties and delays in refilling the lake basin to pre-drawdown levels.

Water level manipulation – high lake levels

Water levels in Blue Lake can fall as much as 30 inches in mid to late summer due to evaporation and little or no rainfall. For the last decade, Metro has purchased water from the City of Portland to maintain normal lake levels. This practice does not suppress plant growth. It does improve lake aesthetics and less weed entanglement seems to occur (Interlachen Homeowners, pers. comm.) because most of the plant biomass remains below the surface when water levels are high. The drawback is that the water used as a summer supplement comes from the City of Portland well field near Blue Lake. Groundwater from these wells is is at least as high in nutrients as the lake water. The groundwater from the wells may contribute to increased algal productivity and subsequent high pH levels in Blue Lake although it may not be possible to determine just how much.

Table 4. Summary of physical weed control methods and suitability for Blue Lake

Description	Advantages	Disadvantages	Suitability
Hand Pulling or Cutting	•Inexpensive •Minimum impact on native plants	•Labor intensive •Slow	• Useful around and on bottom barriers
Bottom Barriers	•Site specific •Reusable ▪ Inexpensive ▪ Easily constructed	•Somewhat labor intensive •Not species specific	• Practical near private docks

Diver harvesting	•Species specific •Entire plant is removed •Relatively compact equipment	Slow ▪Costly	•Useful around private docks and as followup to other treatments
Water level manipulation - drawdown	▪Can be cost effective ▪Beneficial to some native plants	▪ Requires freezing temperatures ▪Damage to retaining walls, docks ▪Impacts to aquatic organisms	▪ Not recommended for Blue Lake
Water level manipulation – keeping lake levels high	▪Improves lake aesthetics ▪Reduces weed entanglement	▪May contribute to algal productivity and resulting water quality problems	▪Not appropriate for an integrated plan due to possible stimulation of algae blooms

Mechanical Controls

Plants may be managed using mechanical methods such as sediment agitation devices, rotovators/cultivators, and harvesters (Table 5). Mechanical methods remove plants and cause varying degrees of fragmentation that can allow some plant species to become re-established when the fragments settle to the bottom.

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Sediment Agitation

Sediment agitation is an automatic plant control method that mechanically disturbs the lake bottom to remove aquatic plants and prevent regrowth within a well-defined area. The machines sweep, roll or drag repetitively over the sediment and plants growing there. They need to be attached to a dock or post and require electricity. There are three main types of sediment agitation machines: weed rollers, lake sweepers, and beach groomers. Weed rollers consist of a long metal cylinder or pipe that rotates forward and backward in an arc along the bottom of the lake. It is powered by a low voltage motor and moves in an adjustable arc of up to 270 degrees. Fin-like projections on the roller help dislodge plants and roots from the sediment. Lake sweepers have two long poles with lightweight rakes attached to the poles. A submersed pump powers the rotating arms, causing the rakes to sweep along the bottom and remove plants within a radius of about 24 to 42 feet. The beach groomer consists of two seven foot arms that are rotated by a pump. The arms have chains attached to them which drag along the bottom to keep the area clear of plants.

The ease of installation and movement varies with the unit. It is best to install and begin using the systems early in the spring before active plants growth begins, as some units do not work well after plants have already grown up. After an area is cleared, the units can be used as little as one day per week to keep the plants from recolonizing. When the units are being used, signs should be posted in the area to prevent people from using the area and to prevent injuries. When not in use, the units should be stored where people cannot accidentally injure themselves.

Costs vary depending on the product. Beach groomers start at about $1,000 and the pump to power it costs an additional $300. Lake sweepers and weed rollers start at about $2,000. The cost for permits from DSL would be extra. Appendix B contains contact information for some vendors of these devices.

If landowners share a sediment agitation unit, the 50 cubic yard ODSL permit limit will apply to the area as a whole. Individual landowners may purchase and use individual sediment agitation units without a permit from ODSL as long as their use has not altered more than 50 cubic yards.

Rotovation

A rotovator works like an underwater rototiller and has blades that till seven to nine inches into the sediment to dislodge and remove roots. The plant fragments that are created in this process can be removed from the water by using a rake attachment or by manual collection. Rotovation is used mainly in the winter and spring to control Eurasian watermilfoil (*Myriophyllum spicatum*). It has also been successfully used to remove the rhizomes of water lilies in Washington (WDOE, 2003). It works best if plants have not reached their mature length as longer stems wrap around the spinning blades and may damage the equipment. If rotovation is to be done later in the growing season, plants may have to be cut prior to that. Obstacles on the lake bottom (logs, large rocks, etc.) may have to be moved and underwater utilities (gas, water, sewer, telephone, water intake pipes, etc.) may have to be located prior to rotovation.

Rotovation removes roots and other plant structures from the sediment which can be advantageous, depending on the target plant species. Waterlilies, for example, form networks of thick rhizomes in lake sediments. Rotovation causes increased turbidity in the lake water, plant fragmentation, and adverse effects on benthic organisms and fish spawning areas. It can also result in the release of nutrients and other substances from sediments.

Any disturbance of greater than 50 cubic yards of sediments of will require a permit from ODSL and, potentially, mitigation for that alteration. At a depth of seven to nine inches, an area of approximately 1800 to 2300 square feet could be done on an annual basis without requiring a permit from ODSL.

Rotovation is not appropriate for use in Blue Lake for several reasons. The target species in the lake are not species which are managed effectively with this method. The turbidity and release of nutrients from the disturbed sediments would further impair water quality in the lake.

Mechanical harvesting

A mower cuts aquatic plants below the water surface but does not harvest the cuttings. Dispersal in a waterbody of cut fragments of a species which readily forms new plants from fragments, such as Eurasian watermilfoil, usually results in increased population size. Cut biomass from species that do not reestablish from fragments, such as curlyleaf pondweed, pose a different problem. A large “pulse” of decaying biomass in a waterbody is a nutrient source for aquatic microorganisms. Dissolved oxygen is the energy source upon which these organisms depend for breaking down and consuming this organic matter. High nutrient inputs typically result in increased biological oxygen demands (BOD) and, if BOD is high enough, oxygen levels in the water column can fall below levels required by fish and other organisms. If BOD levels fall low enough, fish kills will result.

A harvester retains the cuttings on board and offloads them onto an on-shore conveyor belt for upland disposal. A harvester was used in Blue Lake in summer 1971 to remove aquatic weeds from the lake. It was fabricated by Multnomah County personnel and its design was based on one made commercially in Wisconsin. This harvester had cutting knives only at the end of the conveyer belt (The Oregonian, 1971). More modern harvesters have cutting knives on both the front and the sides of the belt. The newer design minimizes the amount of cuttings that escape the harvester. The old harvester allowed cuttings to fall off the side of the belt and re-establish elsewhere in the lake (Guy Swartz, Multnomah County retired, pers. comm.).

Lake Oswego Corporation owns an aquatic weed harvester and has used it successfully for management of curlyleaf pondweed and American waterweed in Lake Oswego. They report that plant fragments are not lost during transport to shore unless there is a long transport distance coupled with choppy water conditions (M. Rosenkrantz, Lake Oswego Corp. pers. comm.). Curlyleaf pondweed does not reestablish from plant fragments although any turions present on plants could be spread. If turions were dispersed, then curlyleaf pondweed could spread to previously uninfested areas of the lake. American waterweed does regenerate from fragments and it is possible that fragments of this species could be dispersed to and establish in the few suitable areas of the lake not already colonized.

The City of Tigard has regularly contracted for mechanical harvesting to keep Summerlake clear of aquatic macrophytes. The cost for harvesting last June was $7500 for approximately 4 acres and yielded 40 to 80 cubic yards of biomass. Harvested biomass was disposed of through a yard debris recycler at additional cost to the city (Steve Martin, City of Tigard Parks Div., pers. comm.). Cost estimates for harvesting in individual lakes are site specific and are based on a site visit by the contractor.

Table 5. Summary of mechanical weed control methods and suitability for Blue Lake

Description	Advantages	Disadvantages	Suitability
Sediment agitation	•Low operating cost •Suppresses plant growth over time	•Plant fragmentation ▪High initial cost ▪May need permit	•Useful around private docks
Rotovation/ Cultivation	•Winter treatment can minimize impacts on recreation	•Plant fragmentation •Bottom disturbance ▪May need permit/mitigation •Large Machinery	•Not suitable due to sediment disturbance, plant fragmentation
Harvesting	•Immediate plant removal •Minimum bottom disturbance ▪Permit not needed	•Plant fragmentation •High disposal cost •Large machinery	•Could be used to keep boat lanes clear

Biological Control

Biological control methods for submersed aquatic plants are limited. There is a native weevil, *Euhrychiopsis lecontei*, which feeds only on plant species belonging to the genus *Myriophylllum* (i.e., milfoil). Although the weevil has the potential for cost effective control of milfoil, it is still considered experimental. No selective biological control agents as yet exist for curlyleaf pondweed (*Potamogeton crispus*), American waterweed (*Elodea canadensis*), or the small leaved pondweeds (*P. foliosus, P. pectinata*). The only biocontrol agent currently available for control of these species is the grass carp (Table 6).

The grass carp (*Ctenopharyngondon idella* Val.) is an introduced species of fish which will eat many aquatic plant species and thus is considered a non-selective method of biocontrol. Only triploid grass carp, which are sterile, are legal to use for aquatic plant control. These fish are non-selective herbivores, although they have definite food preferences which can vary depending on the particular mix of aquatic plant species present. The carp are also sensitive to disturbance and generally do not feed in areas of high human disturbance (e.g., boating, water skiing). They do not forage during winter but are typically active during the warmer months when human use of lakes is high. If nothing else is available, the carp will forage in the sediments for organic matter which can cause increased turbidity levels.

Under Oregon Department of Fish and Wildlife rules, sterile grass carp have been permitted in irrigation canals and privately owned lakes, ponds, and reservoirs no larger than 10 acres which are not located in a 100 year floodplain. The Oregon Fish and Wildlife Commission recently amended these rules to allow exceptions to the water body size limit and the floodplain requirement, provided that the applicant can ensure that the grass carp are unable to leave the water body. Each exception must be approved by the commission on a site-by-site basis (ODFW, 2003).

Devils Lake, near Lincoln City, where grass carp were introduced in 1986 for evaluation, was an earlier exception to these rules. By 1994, grass carp had eliminated all vegetation in the lake, which resulted in a decline in warm water fish populations that require plant cover for habitat.

Grass carp are considered an all or nothing option (Bonar, et al, 2002). That is, intermediate levels of aquatic plant control cannot be expected from the use of this fish. The “all” result would impact existing fish populations and water quality in Blue Lake’s already water quality impaired system. Neither of these outcomes is consistent with the management goals for the lake. It is not likely that a permit could be obtained since Blue Lake is publicly owned (T. Stahl, ODFW, pers. comm.).

Table 6. Summary of biological weed control methods and suitability for Blue Lake, OR

Description	Advantages	Disadvantages	Suitability
Milfoil weevil	Low cost Low maintenance	Attacks native milfoils Currently under R&D, Populations may be limited in many lakes	Eurasian water milfoil not target plant in Blue Lake
Triploid grass carp	▪Low maintenance	▪“All” or “nothing” result ▪ Increased turbidity ▪Impacts on native biota Difficult to contain	▪Not appropriate for an integrated plan

Chemical

Aquatic herbicides can be a cost effective method of aquatic plant control in lakes. Prior to 2001, aquatic herbicide applicators were required to follow EPA-approved product labels which are regulated and enforced under authority from the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) – no application permit was required in Oregon. In 2001, however, the U.S. 9th circuit Court of Appeals decided in the Talent Case (No. 99-35373) that a National Pollutant Discharge Elimination System (NPDES) permit is required for aquatic herbicide applications.

How the Talent decision will be implemented in Oregon is not yet clear. NPDES permits typically include limits on the quantity and concentration of pollutants allowed in a discharge as well as sampling and monitoring, recordkeeping, and reporting requirements. There are two types of NPDES permits: an "individual" permit issued for a site-specific activity, and a "general" permit issued for a category of activities with similar discharges. In Oregon, the application fee for an individual permit is approximately $10,000 with an annual fee of about $2,500 to maintain the permit. NPDES permits are issued for a period of five years.

The alternative to an individual permit is a general permit, which could be structured in a variety of ways provided that the standard conditions developed in the permit are adequate to protect the environment. A general permit could be developed to allow for a broader use of a particular herbicide on more than one noxious aquatic weed species, or the permit could focus on a specific weed and allow a variety of herbicides to be used. A general permit could be issued to anyone that can meet the terms and conditions of the permit. In Oregon, general permits must be issued through a formal rulemaking process, which may take six to nine months. Permit development costs for DEQ are in the range of $50,000 to $100,000, but the permit application fee is set in rule at approximately $700 with an annual fee of $350. As a result, a general permit is considered only when there is the potential for multiple permittees and thus a reduction in overall administrative costs.

The State of Oregon has not yet developed any general permits for aquatic herbicides. There are individual permits that have been issued for aquatic herbicide treatment of irrigation canals; however, these have recently been revoked. DEQ revoked the permits to comply with an order from the U.S. District Court for Oregon (*Northwest Environmental Advocates v. US EPA*, D.Or.No. CV-01-510HA). The court determined that EPA failed to approve DEQ's "alternate mixing zone standard" and ordered DEQ to revoke all permits that were based on this standard. The irrigation permits used this standard to allow for larger areas of toxicity. While it is not likely that DEQ will issue any NPDES permits for aquatic pesticides in the immediate future, it is reasonable to assume that NPDES permitting issues within the state will eventually be resolved.

Oregon DEQ's current policy is that it will not take enforcement action against aquatic pesticide applications made without an NPDES permit, provided the applications are consistent with EPA guidance (in compliance with FIFRA). Since the Talent decision, Oregon DEQ has issued MAOs (Mutual Agreement and Orders) in lieu of NPDES permits as a regulatory mechanism. Although an MAO does NOT provide any measure of protection against citizen lawsuits, it does demonstrate due diligence on the part of the pesticide applicator which would likely help the applicator if a lawsuit were filed.

The application process and costs for an MAO are the same as those for an individual NPDES permit and can take the same amount of time (~ 6 months). The current priority of DEQ regarding permits is to reduce the backlog of expired permits, so an MAO could conceivably take longer than 6 months to obtain. Oswego Lake Corporation retained legal counsel at significant cost to them to assist in the application process for their MAO. They have obtained an MAO and intend to use aquatic herbicides for control of aquatic macrophytes in the lake. The Corporation has also applied for an NPDES permit, but permit development is on hold until EPA approves the alternate mixing zone standard. Lake Oswego differs from Blue Lake in that it is completely privately owned. Blue Lake is a popular, public lake located on the outskirts of Portland and, as such, it would not be surprising if objections to and lawsuits against aquatic herbicide treatment of Blue Lake were made.

There are very few chemical herbicides registered for aquatic weed control. Of those chemicals that are registered for aquatic use, label restrictions prohibit their application in many situations. Herbicides that could be used in Blue Lake are listed in Table 7. Water column dyes are not labeled for use in lakes so are not included in this list.

Table 7. Summary of chemical weed control methods and suitability for Blue Lake, OR

Description	Advantages	Disadvantages	Suitability
Fluridone	▪Systemic – kills roots and shoots ▪Somewhat selective for species ▪Few use restrictions ▪Low doses effective ▪Negligible risk to wildlife	▪Long contact time required	▪Recommended for use in Blue Lake
Glyphosate	▪Systemic herbicide, kills roots and shoots ▪No label restrictions on swimming and fishing	▪Non-selective for species ▪Affects emergent plants only	▪ Not suitable in Blue Lake because not effective against submersed plants
Endothall	▪Short contact time required ▪Low toxicity to fish (Aquathol® formulation)	•Contact herbicide-does not affect underground portions •Use restrictions for water use ▪Toxic to fish (Hydrothal® formulation) •Temporary effect	• Not suitable in Blue Lake because not effective against submersed plants
2,4-D	•Systemic herbicide •Some species specificity Low toxicity to fish	•Toxic to sediment dwelling organisms	•Not recommended in Blue Lake
Diquat	•Short contact time required	•Contact herbicide-does not affect underground portions •Short-term efficacy •Use restrictions for water use Toxic to aquatic invertebrates	•Not recommended in Blue Lake

Triclopyr	▪Systemic ▪Selective for broadleaved plants No label restrictions for swimming and fishing	▪Not effective on curlyleaf pondweed	Not recommended in Blue Lake
Copper compounds	•Short contact time required •Low cost	•Potential toxicity to mollusks & fish, especially in soft water •Accumulates in sediments	•Not recommended in Blue Lake

Recommended Management Plan

The goal of the Blue Lake Integrated Aquatic Vegetation Management Plan is to control nuisance aquatic vegetation so that:

- human recreational and aesthetic use of the lake is facilitated,
- acceptable water quality conditions are maintained,
- natural functioning of lake aquatic systems is not impaired, and that
- monitoring of efficacy permits modification of the plan as it is implemented.

These goals can best be met by preventing new weed introductions and a combination of small-scale physical and mechanical methods and larger-scale chemical treatment. Because the necessary permits for using aquatic herbicides cannot be obtained before the next growing season, a short-term strategy is recommended that can meet some of the management goals. The short-term strategy focuses on implementing aquatic vegetation management techniques that are effective around docks and waterfront in combination with mechanical harvesting to maintain boating access to open water areas. The long-term strategy includes use of selective herbicides to manage nuisance aquatic vegetation along with the small-scale, treatment around docks, if necessary. Recommended techniques for the short and long-term strategies are summarized in Table 8.

Table 8. Summary table of short and long term management strategies for Blue Lake, OR.

SHORT TERM STRATEGY		LONG TERM STRATEGY	
*	Prevention	*	Prevention
*	Bottom barriers	*	Bottom barriers
*	Hand pulling/raking	*	Hand pulling/raking
*	Sediment agitation	*	Sediment agitation
*	Mechanical harvesting	*	Chemical control
*	Monitoring	*	Monitoring
*	Permit development	*	Permit maintenance

Short term strategy

Prevention

Preventing new introductions of aquatic weeds is critical to short and long-term management of aquatic vegetation in Blue Lake. An aggressive homeowner and public education program should be implemented. Homeowners should be made aware of the consequences of introducing plants and fish into the lake through a brochure and at regular homeowner association meetings.

Boats launched in Blue Lake following use in other weed-infested lakes may introduce new nuisance plants to the lake. Signage instructing boaters to clean their boat and trailer prior to launch and upon leaving Blue Lake should be installed at the boat ramp.

Small scale management: Bottom barriers, hand pulling/raking, sediment agitation

Hand pulling/raking, bottom barriers, and/or sediment agitation devices should be used for aquatic vegetation management near boat docks. These activities and installations can be implemented by homeowners early in the growing season. Hand pulling and raking will be required several times during the growing season to maintain a weed-free area. Bottom barriers and sediment agitation devices should provide season long control.

Hand pulling and raking may be made more efficient with a coordinated effort. Harvested plant matter could be loaded onto a barge and transported to a large dumpster at the boat dock. Twelve Mile Disposal has offered to provide a dumpster free of charge (Dennis Meyer, pers. comm.).

Bottom barriers may require periodic maintenance during the summer to remove plants that may root on top of the barrier. If removed at the end of the season the barrier may be reinstalled the following year, thus lowering the amortized cost. Barriers can be installed by homeowners or a contractor.

Dock-mounted, sediment agitation devices are relatively new technology and long-term durability and efficacy have not been evaluated. The devices are simple, especially the rake devices and, if the lake bottom is clear of obstructions, maintenance should be minimal.

Bottom barriers and sediment agitation devices are easiest to install and most effective when placed in the lake before spring plant regrowth begins (March in Blue Lake). Installation of either of these devices is far easier when plant biomass is minimal and, in the case of sediment agitation devices, effectiveness is maximized. Signs will also have to be posted to alert people to the presence of these devices in the waterbody.

Large scale management: Mechanical harvesting

Mechanical harvesting is recommended to maintain boat lanes between boat docks and open-water areas until a herbicide application permit can be obtained. Multiple harvests during the growing season will probably be required to maintain uninhibited access to open water.

A harvester could be purchased or leased by homeowners and/or METRO, or a private firm could be contracted for harvesting activities. Given the high cost of purchase and operation and the interim nature of this treatment, leasing or contracting is recommended. The Lake Oswego Corporation owns a harvester and associated plant biomass handling equipment that may be available for lease in 2004 (Mark Rosenkranz, pers. com.). Homeowners and/or METRO would be required to furnish an operator and necessary insurance.

Contracting with a private company for mechanical harvesting may be the simplest approach. Typical costs range from $1500 to $2000 per acre harvested, although costs are dependent upon distance to off-loading site, plant density, etc. Harvesting 4 acres of aquatic weeds in Summmerlake cost $7,500, plus additional for disposal of harvested biomass. As noted above, two cuttings will probably be necessary to maintain access to open water throughout the summer.

Permit development

According to the U.S. Ninth Circuit Court of Appeals, development of an NPDES permit is required for application of aquatic herbicides. The NPDES permit application must include a public comment period and a clear description of the chemical options, application technique, public notice, and monitoring. A NPDES permit is recommended instead of a MAO to reduce risk of a third-party lawsuit over herbicide application in this urban lake. Obtaining a permit could require several months; therefore, permit development should begin in early 2004 to allow implementation of the long-term strategy in 2005.

Long-term strategy

Prevention

Boat ramp use should be monitored. A boat washing station and inspection prior to launch may not be appropriate at this time because of low use of the ramp. However, these options should be reevaluated if use increases. Homeowners and METRO should also support formation of county weed boards and statewide and regional efforts to prevent movement and introduction of aquatic invasive species.

Small scale management: Bottom barriers, hand pulling/raking, sediment agitation

Bottom barriers, hand pulling/raking, and sediment agitation are also part of a long-term strategy for aquatic vegetation management. These techniques can provide high-intensity control of vegetation around boat docks and swimming areas. These techniques reduce the size of the area targeted for chemical control and may also be used in conjunction with chemical treatment to ensure season-long control.

Contact herbicides, such as Endothall or Diquat, could also be used on a small scale to provide the high intensity macrophyte control needed close to docks and swimming areas.

Large scale management: Fluridone treatment

Several aquatic herbicides are licensed for aquatic use (see Table 7). Systemic herbicidal activity on monocots (such as curlyleaf pondweed), however, is only available with fluridone. Fortunately, fluridone exhibits selectivity when applied at low concentrations over long periods, which permits management of nuisance plants without impacting all plants in a lake. Contact herbicides, such as Endothall and Diquat, are available for spot treatment of small areas

Assuming that a NPDES permit can be obtained, a multiple-year application of a pelleted formulation of fluridone (SONAR Quick Release™) using a low-rate, long contact time treatment strategy is recommended to target the curlyleaf pondweed and the small population of Eurasian watermilfoil in the lake. The goal of the treatment should be to maintain a concentration of 5 to 10 ppb in the treatment areas over an eight-week period. This treatment regime will minimize impacts to the native aquatic plant species. Because hydrolysis and photolysis can rapidly reduce the concentration of fluridone in water, split applications of SONAR Quick Release™ pellets will be required at approximately two to three-week intervals to maintain the target concentration and contact time. The sum of all the split applications would be less than the maximum allowable application rate of 150 ppb.

Immediately following the initial treatment and at two-week intervals, lake water samples will be collected by the applicator and assayed for fluridone using FasTEST, an Enzyme Linked Immunosorbent Assay (ELISA) analysis that provides quick turnaround of samples and reliable reporting of concentration in the lake water. Following the second and subsequent samplings, fluridone concentration will be boosted to add only enough material to maintain the target concentration in the littoral areas. The advantage of the Quick Release™ formulation is its ability to concentrate the fluridone in areas of the lake having the most nuisance vegetation. Some mixing and transport of the herbicide into other portions of the lake is inevitable and, although the whole-lake concentration of herbicide will be below the target concentration, it will assist in control of floating plant fragments in nontarget areas.

Low concentration of fluridone over a long period (six to eight weeks) is highly effective against curlyleaf pondweed and American waterweed if applied early in the growing season, i.e. when carbohydrate reserves are low and before a new cohort of turions are produced (Madsen, et al, 2002; Woolf & Madsen, 2003).This treatment regime will provide some selectivity in control and impacts to native aquatic plants should be minimal. Maintaining native plants in the lake is important for fish populations and water quality.

The first year of treatment should target existing curlyleaf pondweed plants that have sprouted after overwintering in the lake sediment. Herbicide application needs to be made very early in the growing season – before the plants form more turions. Data on winter sprouting and growth of curlyleaf pondweed was collected by a PSU graduate student during early 2004. Turions were first found on sampled plants from Blue Lake in early April of 2004. The turions were well developed which indicates that initiation had begun some weeks previous. Sastroutomo (1981) found that turion formation on *P. crispus plants* in a Japanese lake took two weeks.

Complete control of turion formation may not occur with only one year of treatment. A second year of fluridone treatment should be planned that would target any residual curlyleaf plants remaining in the lake. Information obtained in monitoring of plant populations during and after the first year of application should be used to modify timing and fluridone application rate during the second year. Small-scale treatments using hand pulling, bottom barriers, dock-mounted devices, or contact herbicides should continue in the second and subsequent years, if necessary.

Monitoring during and following the second year of fluridone treatment will determine the need for additional chemical application. If nuisance vegetation is under control, then management objectives may be accomplished with only small scale, localized control methods. Aquatic vegetation management will be required in subsequent years, however, and continued monitoring of plant populations and updating of the management plan to reflect the changing status of the aquatic vegetation in the lake will be necessary.

The chemistry and mode of action of fluridone limits toxicity and non-target impacts. Fluridone inhibits carotenoid (yellow pigment) synthesis in plants. Carotenoid pigments protect chlorophyll (green pigment) from decomposition by sunlight. When carotenoid synthesis is inhibited the lack of protective yellow pigmentation causes the chlorophyll to be photodegraded in sunlight. Without chlorophyll, the plant is unable to produce carbohydrates by photosynthesis and the plant is starved of the basic energy producing molecules it needs for growth. Bleaching caused by photodegradation of chlorophyll is the primary symptom of action. Bleaching of stem apices should be evident after 2-3 weeks of fluridone treatment.

Fluridone symptoms may be evident on emergent macrophytes and floating leaf plants, however, at the recommended application rate these plants should survive the treatment and re-establish the year following treatment.

The macrophytes that are killed by the fluridone treatment will not have a significant impact on the oxygen in the lake. If all the plants were to die at one time and begin to decay immediately, there would be a large increase in BOD that may suffocate the fish in the lake. Because of the long duration of the treatment and the gradual death of the plants, the decay process will be spread over at least a 30 to 90 day period.

Water treated with fluridone may not be used to irrigate established turf or row crops, newly seeded beds, or areas to be planted including overseeded golf course greens (when above 5 ppb). At the recommended treatment rate, there are no other restrictions on use of fluridone-treated water. The lake can be used for swimming, boating, and fishing with no restrictions on eating the fish immediately following application of fluridone.

Monitoring

As noted above, monitoring is an important element of an integrated aquatic vegetation management plan. Regular monitoring of plant populations and water quality will enable modification of the management plan to accommodate changes in the lake that occur following implementation of management actions.

Aquatic plant surveys should be done twice per summer. An earlier survey (May) would focus on detecting curlyleaf pondweed while a later survey (August) would focus on Eurasian watermilfoil. Both surveys would also serve to detect pioneer infestations of aquatic weed species not already present in the lake. Plant surveys could be easily done using a rake for a sampling device. Lake access could be from the small boat docks ringing the lakeshore or from small boats. Surveys could be accomplished by Metro park maintenance personnel and/or homeowners. The entire lake would not have to be surveyed, rather, detection efforts should focus on the shallow east and west ends of the lake. Plant samples must be identified to species and regrowth of treated plants or pioneer infestations of new plant species treated early. Early detection of regrowth and/or new invaders should make it possible to use small scale treatment techniques to control them.

Monitoring should also include monthly measurement of transparency; profiles of dissolved oxygen, pH, temperature, and specific conductance; epilimnion and hypolimnion concentrations of chlorophyll *a*, NH_3, NO_3+NO_2, TKN, SRP, and TP from June through September.

Because cyanobacteria blooms have occurred in the lake, phytoplankton should be sampled every two weeks during the summer for characterization of species abundance. When potential toxin producing species are present, anatoxin and microcystin concentrations should be measured. A toxic algae response plan should also be developed that provides a clear protocol for action when potentially toxic algae are present in this high-use lake.

Zooplankton populations are influenced by availability of cover by aquatic plants and they can influence phytoplankton populations through grazing. Epilimnion zooplankton samples should be collected with phytoplankton samples. If funding is not currently available for analysis, these samples may be archived for later analysis.

Prevention

Preventing new introductions of aquatic weeds is critical to short and long-term management of aquatic vegetation in Blue Lake. An aggressive homeowner and public education program should be implemented. Homeowners should be made aware of the consequences of introducing plants and fish into the lake through a brochure and at regular homeowner association meetings.

Boats launched in Blue Lake following use in other weed-infested lakes may introduce new nuisance plants to the lake. Signage instructing boaters to clean their boat and trailer prior to launch and upon leaving Blue Lake should be installed at the boat ramp.

Funding

Funding for aquatic weed control in Oregon lakes is limited. The Oregon Department of Agriculture has an ongoing weed management grant program that provides funding for implementation of weed control programs. METRO could apply to ODA for funding to implement this management plan.

Table 9. Estimated cost for short term and long term management strategies

	Estimated Cost	Implementing Entity	Note
Short-term Strategy			
Prevention			
Sign at boat ramp	$500	METRO	one-time cost
Brochure for homeowners	$1,500	Homeowners Association	one-time cost
Hand pulling	$500	Homeowners	Assumes $15/hr for 10 hr, 3 times/yr plus rake @ $50
Bottom Barriers	$2,000	Homeowners	Estimated cost for installation of 1000 sqrt ft @2.00/sqr ft, $150/yr ongoing maintenance also required
Dock-mounted Devices			
Roller	$2,000 - $3,000	Homeowners	one-time cost for installation, ongoing maintenance
Permits	variable	Homeowners	Cost is site dependent, some types of permits are no-cost
Rake	$2,000 - $3,000	Homeowners	one-time cost for installation, ongoing maintenance
Harvesting boat lanes	$24,000	METRO	Estimated cost for 6 acres @$2000/acre @ minimum of twice per year
Monitoring	$15,000	METRO/DEQ/PSU	Assumes 0.49 FTE grad student for 6 mo and DEQ lab analysis of samples
Permit Development	$10,000	METRO	Cost estimate based on DEQ cost for individual permit
Long-term Strategy			
Prevention			
Sign at boat ramp	$500	METRO	one-time cost
Brochure for homeowners	$1,500	Homeowners Association	one-time development and printing cost
Hand pulling	$500	Homeowners	Assumes $15/hr for 10 hr, 3 times/yr plus rake @ $50
Bottom Barriers	$1,000	Homeowners	Estimated cost for installation of 1000 sqrt ft @1.00/sqr ft, $150/yr ongoing maintenance also required
Dock-mounted Devices			
Roller	$2,000 - $3,000	Homeowners	one-time cost for installation, ongoing maintenance
Rake	$2,000 -$3,000	Homeowners	one-time cost for installation, ongoing maintenance
Herbicide treatment	$30,000	METRO	Annual cost of a two-three year program. Maintenance control as needed in out years will be lower
Monitoring	$15,000	METRO/DEQ/PSU	Assume 0.49 FTE grad student for 6 mo and DEQ lab analysis of samples

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